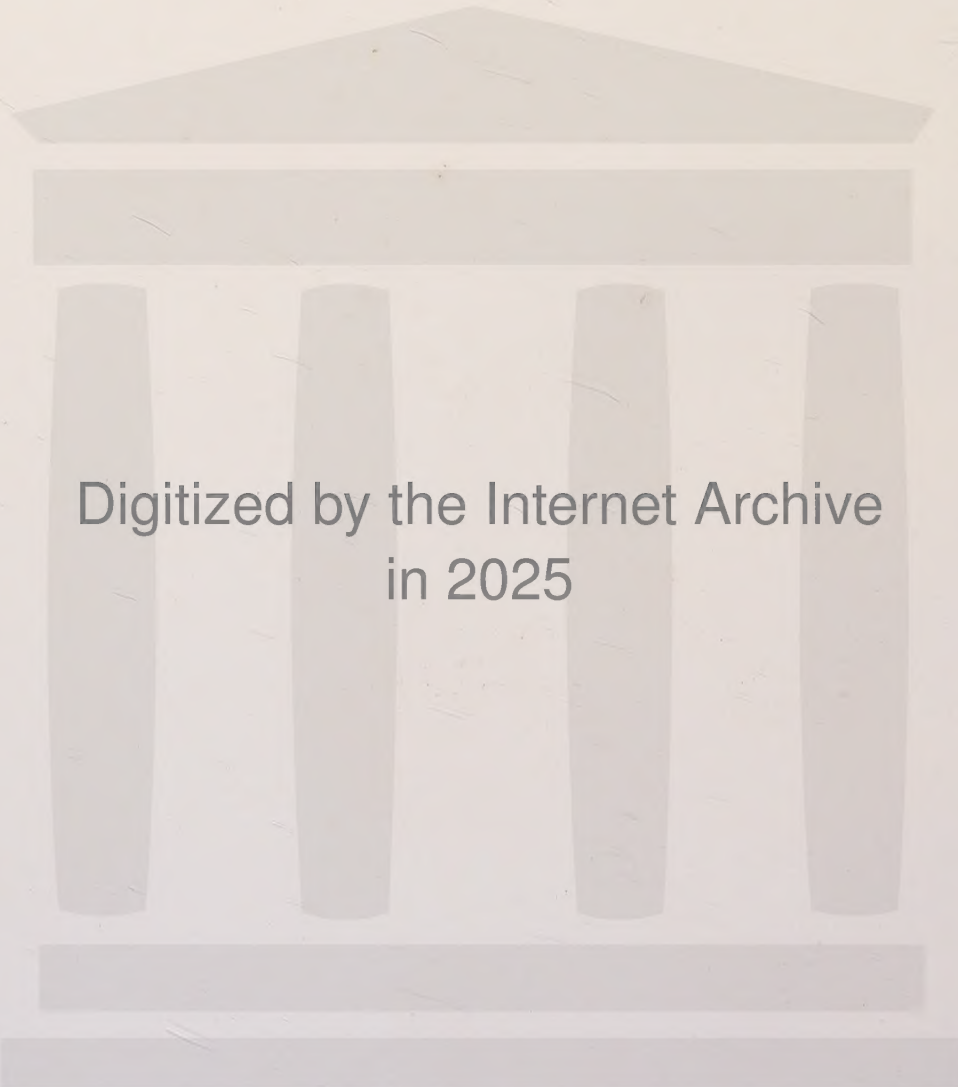


MARINE STEAM





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FORGED STEEL WATER-TUBE MARINE BOILERS

Manufactured by
THE BABCOCK & WILCOX CO.
NEW YORK, U. S. A.
AND
BABCOCK & WILCOX, *Limited*
LONDON, ENGLAND

HIGHEST AWARD, GRAND PRIX, EXPOSITION UNIVERSAL
PARIS, 1900



FIRST EDITION

NEW YORK AND LONDON

1901

MARINE STEAM



THE BABCOCK & WILCOX CO.
NEW YORK.
BABCOCK & WILCOX LIMITED.
LONDON.

PARTLETT & Co. N.Y.

THE BABCOCK & WILCOX CO.

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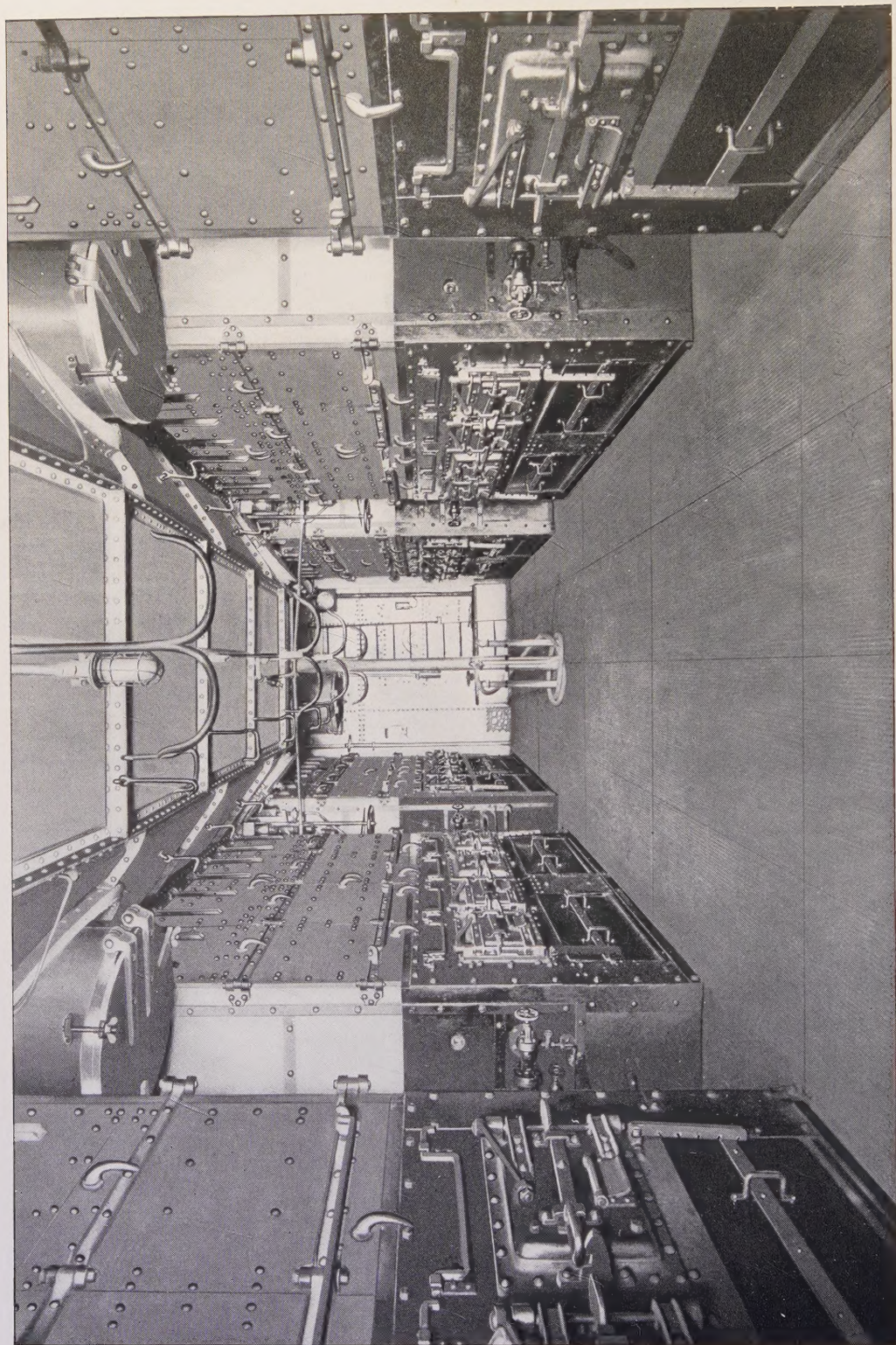
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BABCOCK & WILCOX BOILERS, 5000 HORSE-POWER

THE WATER-TUBE BOILER—STATUS AND HISTORY



THE marine engineer of to-day, conversant with the current technical literature of his calling, is no longer in doubt regarding the position of the water-tube boiler for marine purposes. He is not only convinced that it has come to stay, but is equally sure that it will, at no late date, supplant the boilers of the fire-tube variety in all important steamers on lake and sea.

The question of its advantages and the exploitation of its disadvantages have afforded themes, during recent years, for voluminous discussions both in the technical press and in the proceedings of the great law-making bodies of this and foreign governments.

By these mediums the theoretical side of the question has become too familiar to admit of further general interest, and the practical side of the radical change involved alone remains an open and keenly live topic of the times.

It will be a surprise, however, to a great number of even the most advanced followers of this subject, to find that there is nothing at present in the market in the shape of a water-tube boiler that can claim great novelty of design or principle. Indeed, it will be seen from the brief outline of the history of the water-tube boiler, as given in the next chapter, that certain types of these boilers, now being pushed into prominence, have *fac similes* in the archives of the patent office, or are nearly identical with types tried and abandoned as defective years ago.

Persevering effort and abundant capital can secure the commercial test of any type with a theoretical claim for efficiency. The type that will endure, however, must appeal to engineers through actual practical advantages both in the *operation* and in the *care* of the plant. That such permanent advantages do exist in some types of the water-tube boiler is evidenced by the increasing rapidity with which old steam vessels, formerly using fire-tube boilers, are being re-boilered with the water-tube boiler, and, more forcibly, perhaps, by the almost exclusive adoption of this variety of steam generators for the machinery of new war ships throughout the world.

In the *simplest form* the water-tube boiler closely approaches the ideal. It embodies the greatest strength with least steaming weight. It can be constructed in the ship. Its parts subject to wear or destruction (the tubes) can be bought in any market and do not require to be bent to special forms, and can be readily renewed without specially skilled force. There are no furnaces to threaten with dropping crowns, nor any large flat stayed surfaces under pressure and subject to bulging, or annoying and wasteful leaky seams. The speed of steam raising is phenomenal compared with that safely possible with the Scotch boiler, yet an ample body of water for safe and easy operation

is not precluded. It is not injured by "forcing," nor is it difficult to preserve in a practically constant state of efficiency. It is not therefore wonderful that its claims have demanded and received definite recognition and that it is no longer an experiment.

The great point of difference in the several types of water-tube boilers now on the market, lies in the character of the tubes used. These are either simple straight tubes, simple bent tubes or compound straight tubes, the latter being constructed with a smaller tube inside of each main tube for the purpose of promoting circulation, one end of each main tube being closed.

The bent-tube type comprises a great variety of designs, the tubes being either actually bent to certain sinuous forms, or by use of elbows or return bends in connection with short sections of straight tubing.

The bent small tube variety has obtained great prominence in torpedo boat work, where every sacrifice must be made to *lightness* for greatest power and for speed of raising steam. The objections raised to this type are no secrets, and they lie in the practical difficulty of *retubing*, and in preventing loss of feed (and consequent burning out of tubes) when operated by a force not specially trained. This latter is due to the small body of water in the boiler. The inaccessibility of the tube ends for outside cleaning and preservation from corrosion by wet ashes and dirt is among the "cons" to be considered.

Both for war ships and merchant marine vessels the simple straight-tube type seems to best meet the requirements, and the present tendency is to show increasing preference for this kind of boiler. The advantages are so obvious as to make the selection a most natural one. The points of merit, in detail, will be shown later on.

Of late it has been the fashion of some writers antagonistic to the success of the water-tube boiler to claim, inferentially at least, that the old-style cylindrical boiler possessed all virtues and no defects, and to point with trembling pen at the frightful havoc ensuing from the introduction of even the smallest quantity of salt feed in the water-tube boiler. There is no room for expounding the dangers of salt feed or any other dangers attending the cylindrical boiler service; they all are aged and familiar, but we can properly refer to an interesting statement made by Mr. Wingfield in a speech before the Institute of Naval Architects at Newcastle, wherein he states that not only may water-tube boilers have a certain proportion of salt water mixed with the feed, but that one vessel made a large part of the voyage to South America wholly with salt feed.

This reference is not quoted for misleading purposes, as all marine engineers concede the criminality of purposely using salt feed, be the boiler of shell or water-tube type, but it is noted simply as a fact confuting the statements of the ultra conservative holders to the fire-tube boiler, and goes to show that with a water-tube boiler properly designed and constructed, even the bugbear of salt feed fails to materialize as a forbidding reality.

After the recent war with Spain, it was found necessary to renew the furnaces of the battle ship "Indiana," requiring the services of not only the New York yard with its gang of boiler makers, but the furnaces had to be corrugated in a particular shop; all this detained the ship at the yard for four months. Had the "Indiana" been equipped with say ten water-tube boilers of the straight-tube type, the tubes being expanded into place with ends accessible, the first three rows over the fire might have been removed and replaced, whether blistered, burned and bent from salt and oil in the feed or from any other cause, and repairs made, entirely by the ship's talent, in not more than three weeks' time.

One of the largest firms shipping ore from Lake Superior, equipped a few years ago a new 6000-ton freighter with water-tube boilers, and, when asked what they considered one of the greatest advantages attained by the use of these boilers, replied: "We can load our vessels at the rate of a thousand tons an hour and unload them almost as quickly. This means that our stay in port is only a little over six hours. In that time we can blow a boiler down, make a joint on boiler steam piping, grind in a leaky safety valve or renew a tube; can refill and have full steam and be ready to sail for destination as soon as the ship is loaded, and yet have no fear of straining the boilers from unequal expansion in getting steam quickly. With our old cylindrical boilers we would just about have them cooled off ready to work upon by the time the ship was loaded, and the rest of the time occupied upon the repairs, refilling, and slowly raising steam, means detention of the ship and loss to us."

On the great lakes of North America, the water-tube boiler is used to a great and constantly growing extent. Here freight is carried cheaper than on any body of water in the world, and the commercial success in the adoption of this type is an assured fact and one of the strongest "cards" in the claims for its advantages.

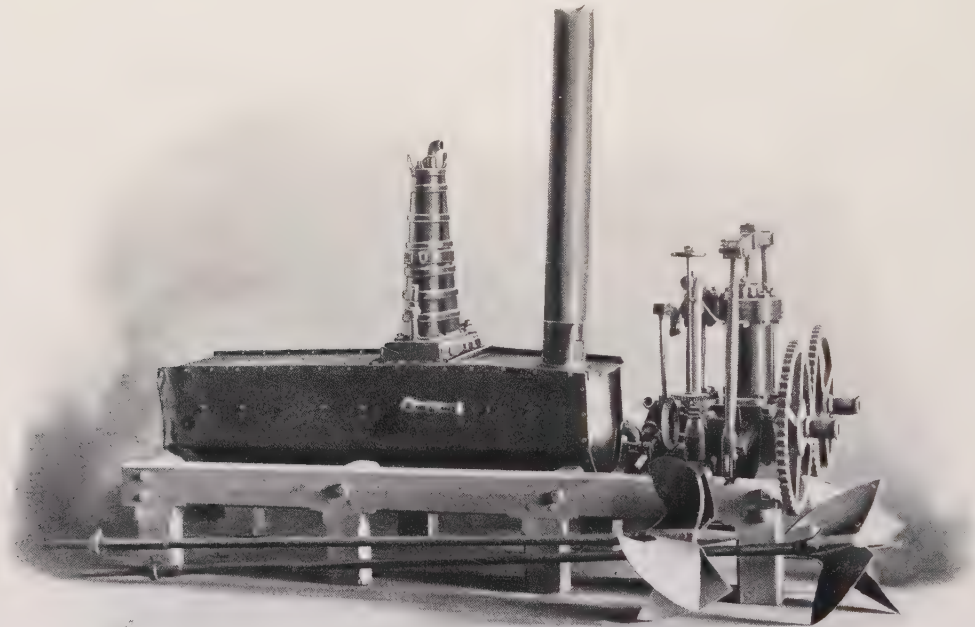


A BRIEF HISTORY OF THE WATER-TUBE BOILER



IN 1804, nearly a century ago, Col. John Stevens built and operated upon the Hudson River a little steamboat, 68 feet long by 14 feet wide.

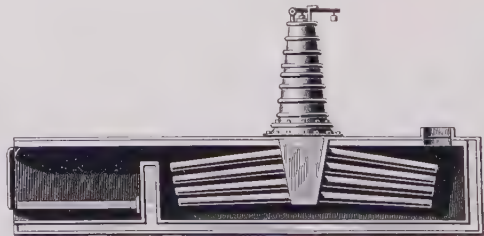
The machinery of this vessel consisted of a single upright cylinder whose piston rod moved up and down a cross head, which in turn drove two cranks by means of connecting rods. From the cranks a pair of shafts led aft, and were fitted with twin screws.



MACHINERY OF STEVENS BOAT, 1804

Steam was supplied by one water-tube boiler, containing 100 tubes, 2 inches in diameter and 18 inches long. One end of each tube was fastened to a central water leg, the other end being closed. The hot gases passed around these tubes, the water being inside of them.

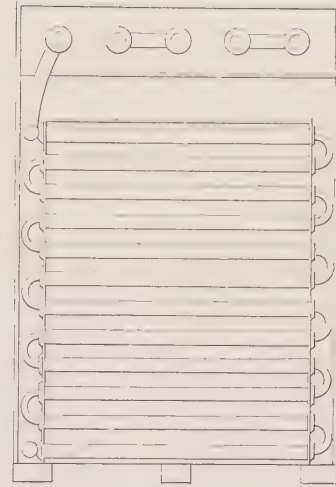
This vessel attained a speed of seven miles an hour and was one of the earliest examples of the use of the water-tube boiler for marine purposes.



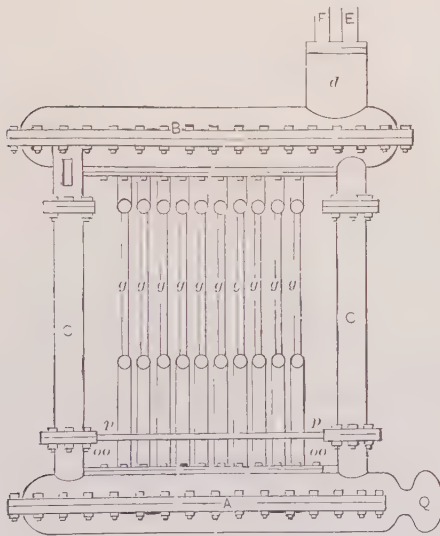
STEVENS, 1804

The first purely sectional water-tube boiler was made by Julius Griffith, in 1821, who used a number of horizontal water tubes connected to vertical side pipes, which were in turn connected to horizontal gathering pipes, and these to a steam drum.

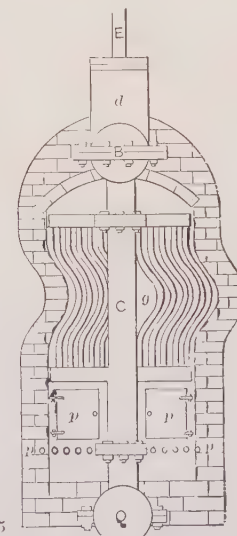
The first sectional water-tube boiler with a well-defined circulation, was made by Joseph Eve, in 1825. His sections were composed of small tubes slightly double curved but practically vertical, fixed in horizontal headers, which were in turn connected to a steam space above and water space below formed of larger pipes, and connected by outside pipes so as to secure a circulation of the water up through the sections and down the external pipes.



JULIUS GRIFFITH, 1821

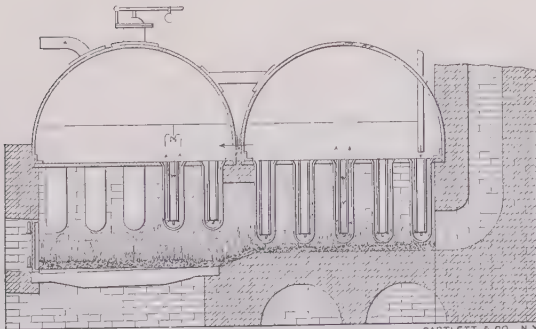


JOSEPH EVE, 1825



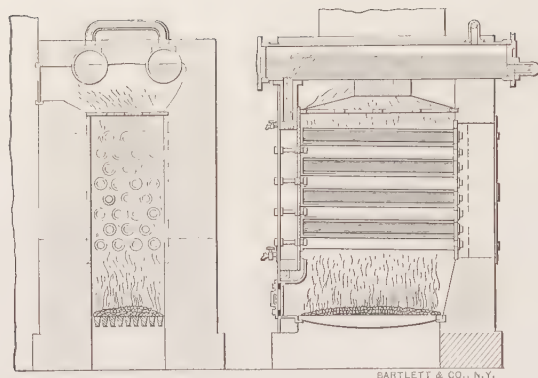
In 1832, Jacob Perkins, of England, invented the inner tube, or lining,

for the purpose of obtaining a rapid circulation. He applied it to a boiler constructed with a number of closed-end tubes descending from the steam and water reservoir so that each would come into contact with the fire in the furnace and thereby present a more considerable surface to the heat.



PERKINS, 1832

BARTLETT & CO., N.Y.



ALBAN, 1843

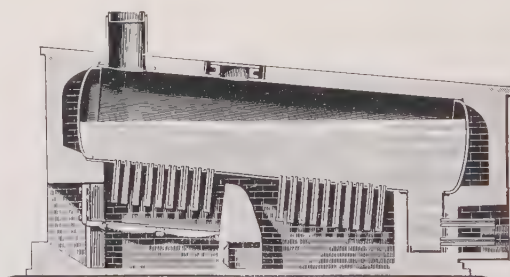
Dr. Ernest Alban, of Plau, Mechlenburg, in 1843, experimented with and built a number of water-tube boilers using the principle of the closed-end tube.

Alban's boilers contained tubes of 4 inches diameter and from 4 feet to 6 feet in length. The rear end of the tube was closed by a screwed cap; the other end being fitted to a groove in the back face of the front water leg and held in place

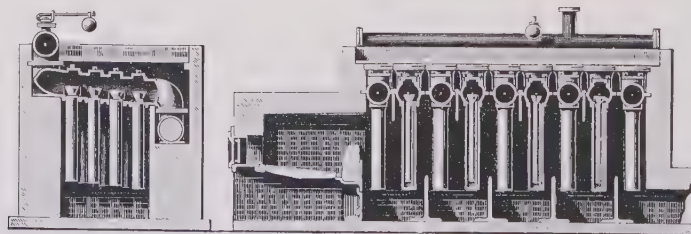
by a T-headed bolt. Two oval openings, one above the other, were made in this back face or tube sheet within the circle of the tube end. The lower opening supplied the tube with water; the upper being intended for the escape of the steam and water from the tube. All tubes were inclined toward the water leg from $\frac{1}{8}$ to $\frac{3}{16}$ inch to a foot, and staggered one above the other, to allow the hot gases to better impinge upon their surfaces.

A few of these boilers were built, but used for experimental purposes and not depended upon for the constant generation of steam.

Collet and Field, in the fifties and early sixties, built a variety of boilers, some with dropped tubes, others with tubes inclined about 45° to the horizontal, and still others with tubes only slightly inclined. A number of these boilers were used in England, but inherent defects existed to such an extent as to cause their popularity to be short lived.

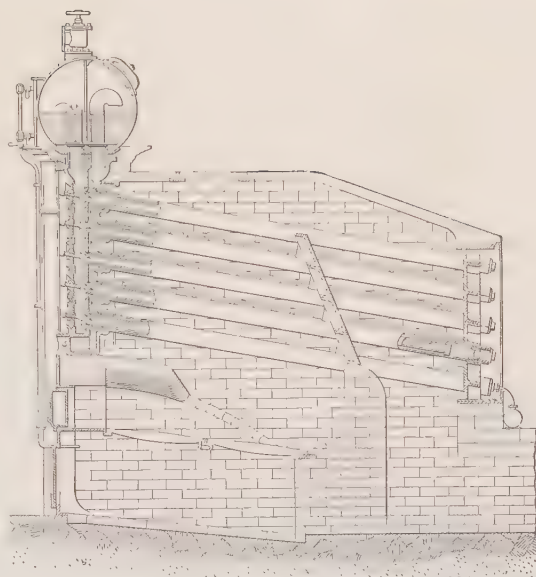


FIELD, 1860



FIELD, 1867

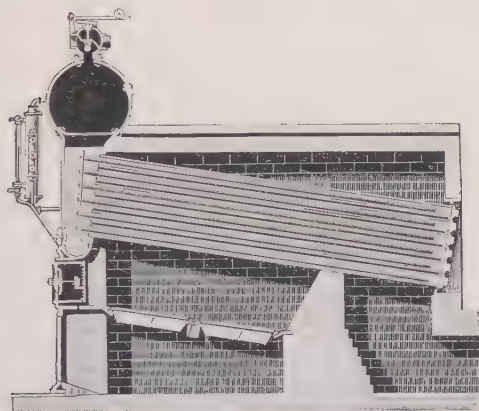
Lane still later endeavored to introduce this closed-end type, using tubes 5 inches in diameter, with an internal circulating pipe $2\frac{3}{4}$ inches. All the tubes were inclined upward toward the front end and were fastened to an upright square chamber, or box, which was divided vertically by a partition that separated the front and rear portions. The internal circulating tube was fastened to this partition, the water to be evaporated flowing down the front side of the partition into the small pipe and around its open end to the outside steam generating tube. Mr. Lane further improved this type of boiler by causing the



LANE

products of combustion to pass twice across the tubes before their exit to the stack. A few of these boilers were built, but as they contained serious drawbacks in design, such as inability to empty the tubes, priming, and enforced low rate of combustion, they soon lost favor and finally entirely disappeared.

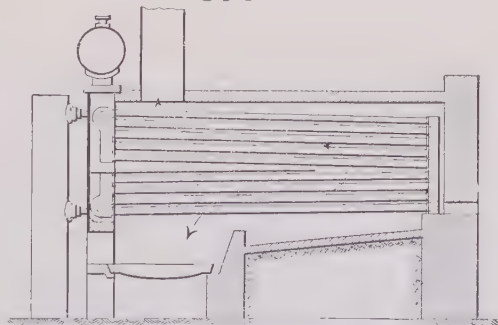
In 1870, J. A. Miller used cast headers to which were fixed closed-end tubes with an inner circulating pipe. These tubes were



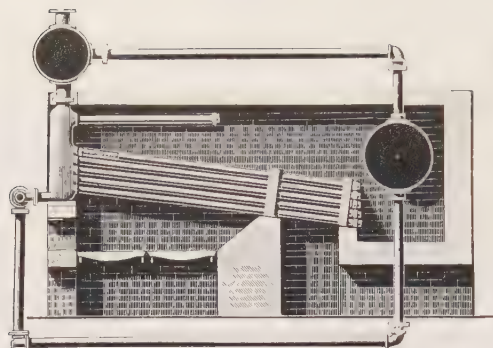
MILLER, 1870

placed at an angle of about 15 degrees to the horizontal and were of such length as to allow of two passages of the gases across them. In this respect Miller followed Lane very closely in design.

In 1876, Anderson, Kelly and Wiegand exhibited at the Centennial Exhibition three different varieties of boilers, each



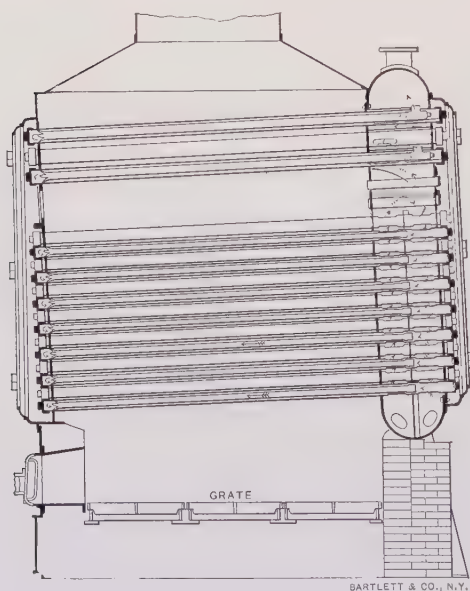
ANDERSON, 1875



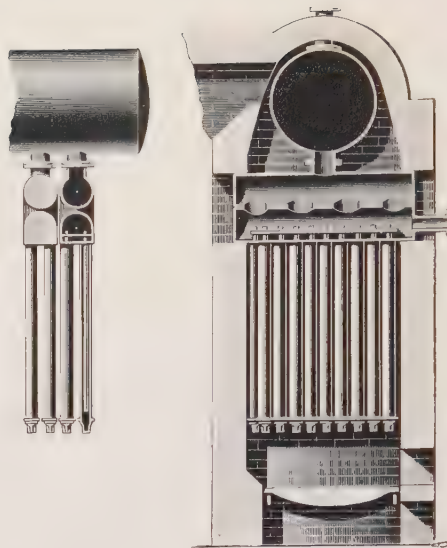
KELLY, 1873

having tubes with one end closed. These boilers were thoroughly tested by a committee of eminent engineers appointed for the purpose, and all made a good showing as far as evaporation was concerned, but they lacked the essential features so necessary in a steam boiler intended to meet all requirements, and a very few years later found them only mentioned in history.

In 1885, Thomas Morrin redesigned for the n^{th} time the closed-end tube boiler. With the advent of the triple-expansion engine came the demand for higher steam pressures, to cope with which the inventor constructed the water slab of his boiler entirely of steel plate.



MORRIN, 1885



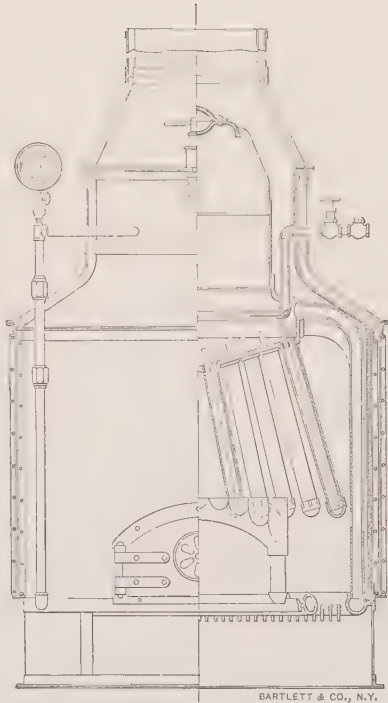
WIEGAND, 1872

The tubes were expanded into the inner and outer faces of the slab, and formed in themselves stays for the flat tube sheets. A vertical partition was placed between the front and rear faces, and, together with the 2-inch inner tubes, directed the circulation. Openings or slots were made in the outer or 4-inch generating tube, on each side of the vertical partition, for the inlet of the water and exit of the steam. Several of these boilers were built for manufacturing and electric light plants; but defects that existed since the time of Stevens (1804), and met with by all Morrin's predecessors, again came to the surface and caused the inventor, after much experimenting, to entirely abandon the design.

Charles Ward, in 1887, designed, and afterward built, a number of small boilers using, in combination, tubes with one end closed and curved tubes open at both ends. The former were screwed into the bottom head of a vertical steam and water drum, while the latter connected the drum to a manifold surrounding the grate.

The circulation in the closed-end tube was promoted by means of two $\frac{1}{2}$ -inch pipes passing through a slightly conical iron stopper at the upper end of each tube; one pipe extending downward, directing the water to the lower end of the tube; the other extending upward a distance of six inches, conducting both water and the steam generated to the steam space.

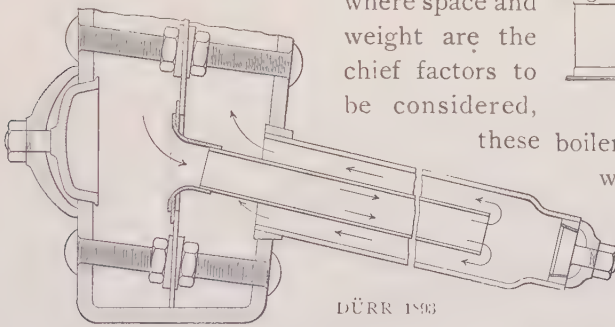
For small launch duty, where space and weight are the chief factors to be considered,



WARD, 1887

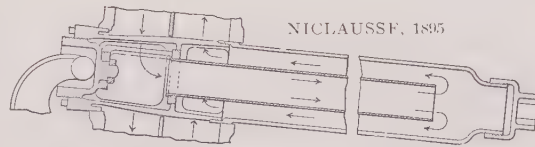
these boilers found service; but they were never entertained for large powers.

Efforts have been made to remove the inherent defects that exist in boilers



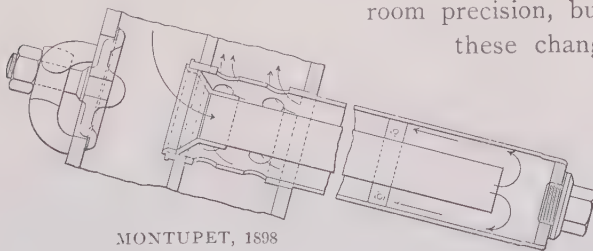
DÜRR 1893

containing tubes with one end closed, by the introduction of specialties of peculiar design, threaded tube ends and conical joints that are ground with tool



NICLAUSSE, 1895

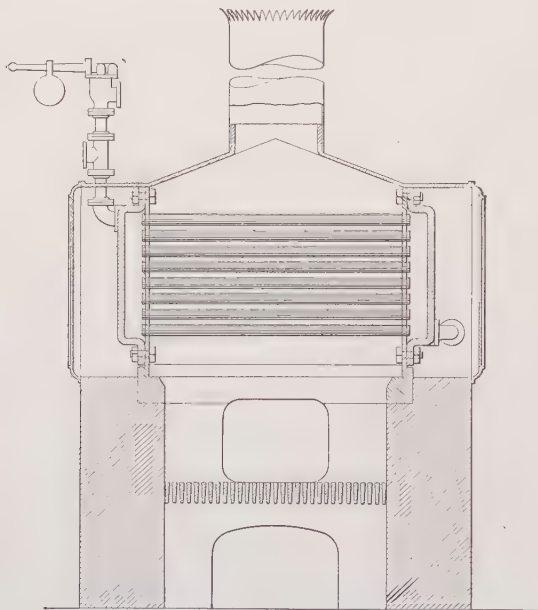
room precision, but in practice the effect of these changes has been to add to the cost of maintenance and increase the labors of the boiler-room staff to such an extent that the remedy was found to be worse than the disease.



MONTUPET, 1898

From the foregoing, it is evident that boilers in which tubes have been fastened into water spaces at one end and left free at the other have been redesigned at a rate of more than one a decade since 1804.

In 1805, Stevens' eldest son, John Cox Stevens, realizing the disadvantages of a boiler containing tubes with closed ends, patented another form of water-tube boiler, which he described as follows: * "Suppose a plate of brass of 1 foot square, in which a number of holes are perforated, into each of which holes is fixed one end of a copper tube of about an inch in diameter and 2 feet long, and the other ends of these tubes inserted in like manner into a similar piece of brass; the tubes, to insure their tightness, to be cast in the plates. These plates are to be enclosed at each end of the pipes by a strong cap of cast-iron or brass, so as to leave a space of an inch or two between the plates, or ends of the pipes, and the cast-iron cap at each end. The caps at each end are to be fastened by screw bolts passing through them into the plates. The



JOHN COX STEVENS, 1805

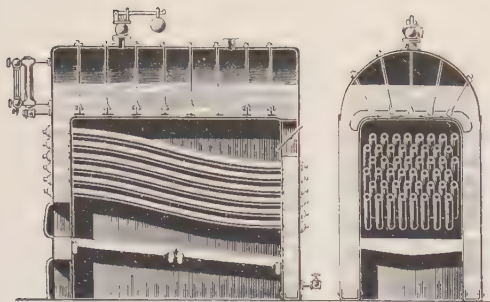
necessary supply of water is to be injected, by means of a forcing pump, into the cap at one end; and through a tube inserted into the cap at the other end, the steam is to be conveyed to the cylinder of the steam engine. The whole is then to be encircled in brick work or masonry in the usual manner, placed either horizontally or perpendicularly, at option."

The circulation was therefore forced, or maintained by the feed pump, the steam that was formed in the tubes being conducted from the opposite space to the engine.

Stevens was led to the belief that water-tube boilers embodied the correct principles of construction, from a series of experiments made in France in 1790 by M. Balamour, under the auspices of the Royal Academy of Sciences. Balamour

states: * "It has been found that, within a certain range, the elasticity of steam is nearly doubled by every addition of temperature equal to 30 degrees Fahrenheit. These experiments were carried no higher than 280 degrees, at which temperature the elasticity of steam was found equal to about four times the pressure of the atmosphere. By experiments which have been lately made by myself, the elasticity of steam at the temperature of boiling oil, which has been estimated at about 600 degrees, was found to equal forty times the pressure of the atmosphere (600 pounds to the square inch). It is obvious that to derive advantages from an application of this principle, it is absolutely necessary that the vessel or vessels for generating steam should have sufficient strength to withstand the great pressure from an increase of elasticity in the

* "Growth of the Steam Engine," Thurston.



WILCOX, 1856

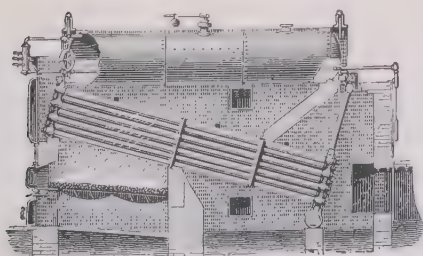
creasing in proportion to the diminution of capacity."

Appreciating the advantages to be gained from this style of construction, Stephen Wilcox in 1856 further perfected Stevens' design by giving to the bank of tubes an inclination and placing overhead a steam and water drum which connected the spaces at each end of the tubes. The necessity for a forced circulation was at once overcome, the steam and water drum forming a reservoir of sufficient volume to maintain a steady water line and give dry steam for the engine.

Late in the sixties, Babcock & Wilcox modified the Wilcox boiler of 1856 (see Babcock & Wilcox, 1868). The water legs were removed and brick sides substituted, the steam and water reservoir being replaced by a cylindrical drum, and, to simplify design, the tubes were made straight.

Although this boiler was constructed entirely of wrought-iron, it contained a very objectionable feature—that of flat stayed surfaces opposite the tube ends.

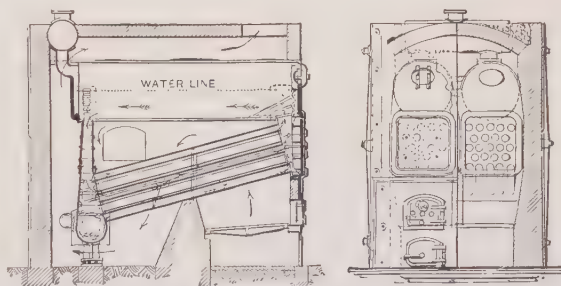
To avoid the use of such stayed surfaces, the now well-known serpentine header or corrugated manifold was substituted in 1873. These headers were first made of cast-steel, and later of cast-iron. They separated the tubes into sections, facilitated examination and repair, and gave to the boiler a flexibility to withstand expansion due to sudden fluctuation in temperature.



BABCOCK & WILCOX, 1873

steam, but this pressure is increased or diminished in proportion to the capacity of the containing vessel.

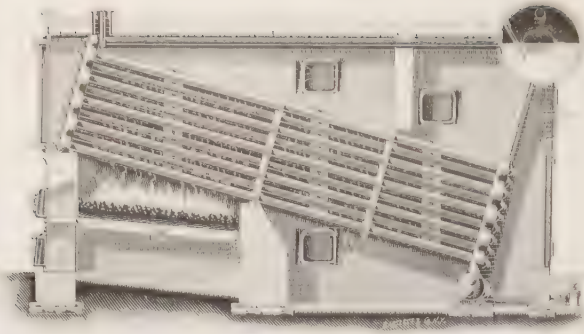
"The principle, then, of this invention consists of forming a boiler by means of a system or combination of a number of small vessels, instead of using, as in the usual mode, one large one; the relative strength of the materials of which these vessels are composed in-



BABCOCK & WILCOX, 1868

In a boiler designed by Babcock & Wilcox in 1881, the longitudinal steam and water drum was placed crosswise and above the lower end of the bank of tubes, the steam and water of circulation entering the drum at the water line, the height of the water in the boiler being at the center line of the drum.

This boiler was not adopted for stationary use until the latter part of the eighties, and



BABCOCK & WILCOX, 1881

was adopted by The Babcock & Wilcox Company in 1889. Short tubes were substituted for long ones, and were expanded into forged wrought-steel corrugated headers, or serpentine manifolds, instead of headers made of cast metal.

Vertical side tubes, backed with light fire tiles and sheet-iron casing, were substituted for brick setting, and the general structure of the boiler materially reduced in weight.

then only in some European countries. Later, with some modifications, it has been extensively used in America, as well as in Europe, and is now in very general operation in stationary plants.

The design was compact, and the reduced height added to its desirability for marine work, for which purpose it



STEAM YACHT "REVERIE"

In 1889, a boiler of this design, built for the steam yacht "Reverie," was made entirely of forged steel, and furnished steam at 225 pounds pressure to a quadruple-expansion engine having cylinders 8, 11, 16½ and 26 inches in diameter by 12 inches stroke. The boiler contained 800 square feet of heating surface and 28 square feet of grate, the engine easily developing 250 indicated horse-power.

The success obtained with the "Kaiser" boiler guaranteed the construction, on the same basis, of a larger boiler having three vertical tubes of heating surface.

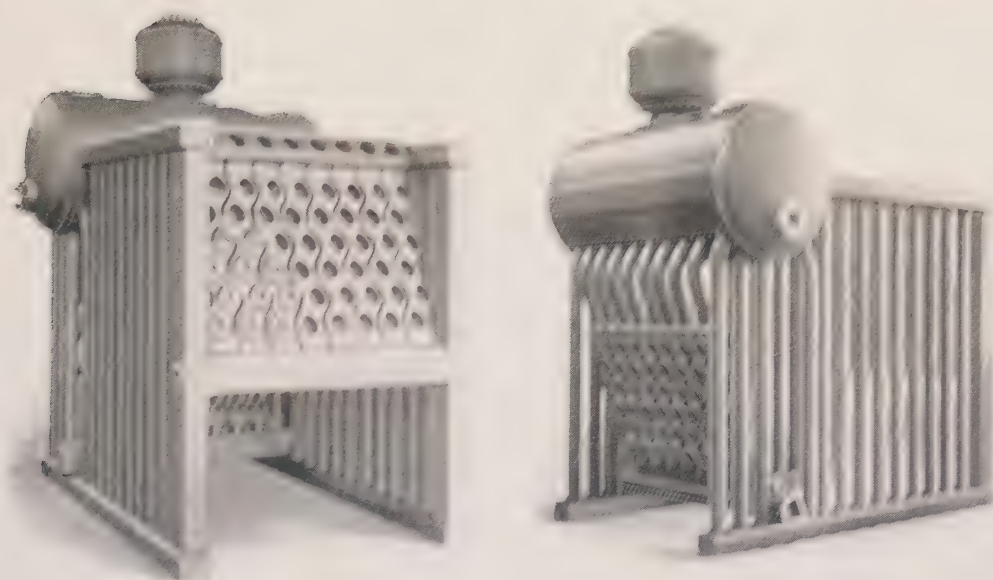


FIGURE 1000. BOILER.

and 24 inches tall in gross. The boiler was built by Messrs. James Watson & Sons, Ltd., Glasgow, and contained a total heating surface of 1,000 sq. ft. The engine room of the experimental type, with cylinders 16 by 24 inches, was built up in a way which allowed the engine to be worked at low pressure and facilitated by the fact that the engine cylinders were worked at low pressure.

The result has been that the engine room is the only one of the kind in the world, and the engine is the only one of the kind in the world, and the engine is the only one of the kind in the world.

In 1892 a boiler was built for the purpose of testing the effect of the engine room on the engine, and the engine was built for the purpose of testing the effect of the engine room on the engine.

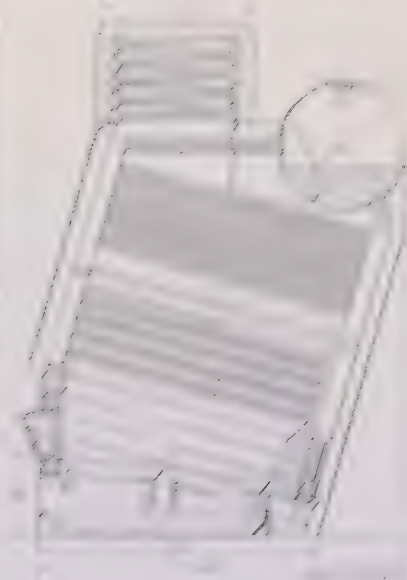
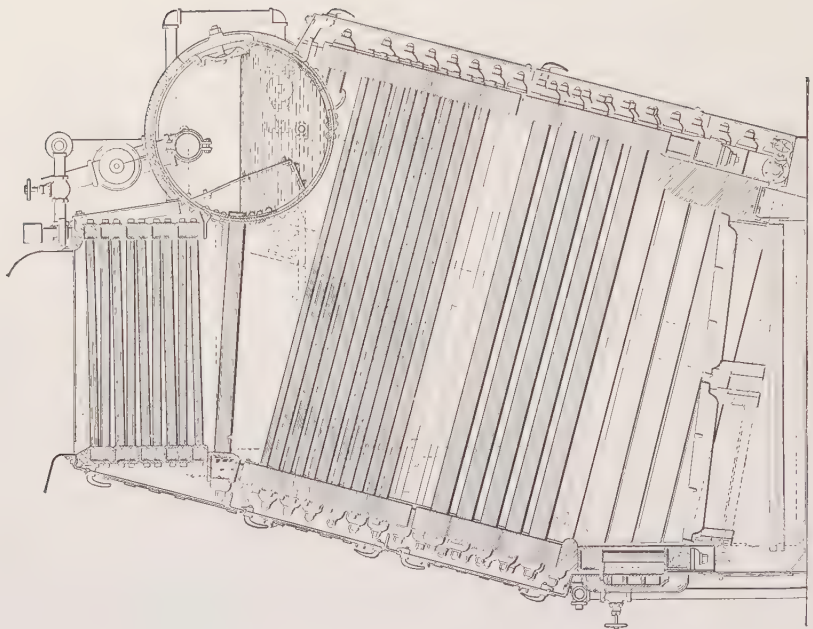
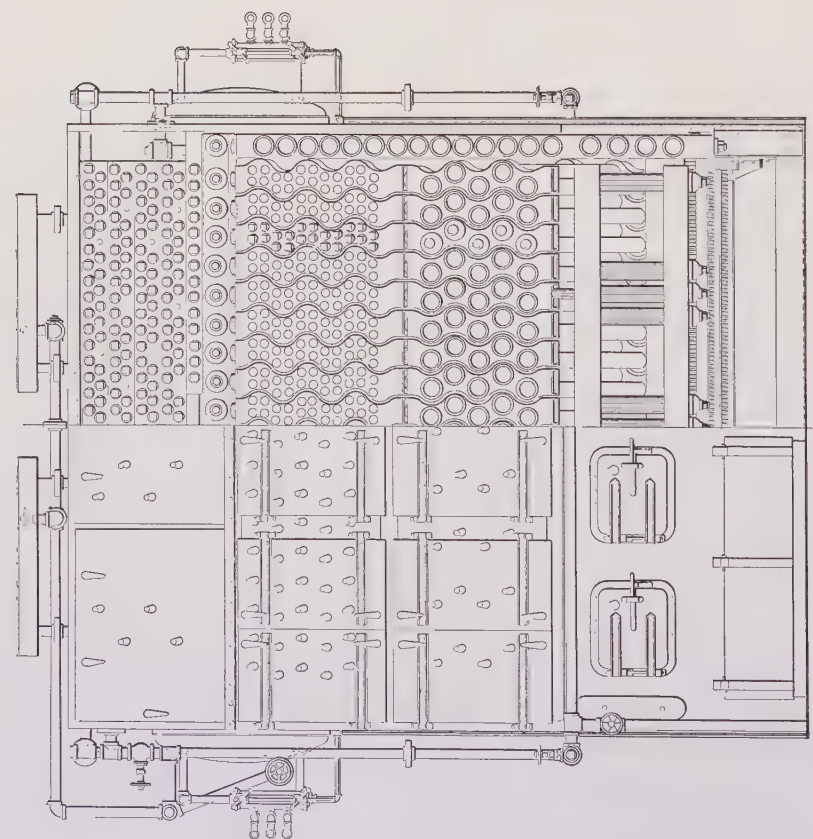


FIGURE 1001. BOILER, 1892.



DESIGN OF BABCOCK & WILCOX WATER-TUBE BOILERS FOR LAKE FREIGHT STEAMER
 "ZENITH CITY," 1895—PATENTED

In 1895 some slight changes were made in the construction of the Babcock & Wilcox boiler in order to increase accessibility. The vertical side tubes were replaced by forged steel boxes at the furnace sides, with tubes above, both boxes and tubes being inclined the same as the sections, the boiler taking the form shown in the cut. (See Babcock & Wilcox, 1895, page 18.)

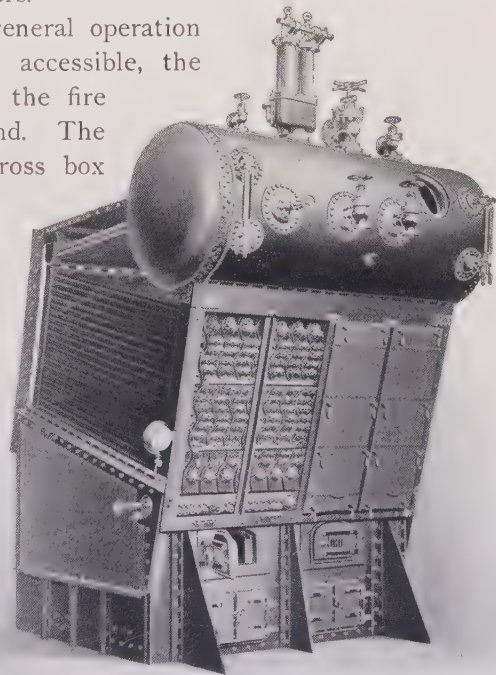
Two boilers of this design were constructed for the 6000-ton lake freighter "Zenith City," the vessel being the largest at that time ever built on fresh water.

The engines were of the triple-expansion type, with cylinders 22, 38 and 63 inches in diameter by 40 inches stroke of piston. These sizes were proportioned to economically expand steam of 225 pounds initial pressure; this pressure being 50 pounds in excess of the ordinary practice in connection with triple engines.

This first installment of water-tube boilers in the lake trade was due to the progressiveness of Mr. A. B. Wolvin. He realized the full value of a device which would reduce the weight, space and cost of operation of the machinery plant of a freight steamer, without reduction of power. He is rightly entitled to be called the "pioneer" in the use of high-pressure steam, water-tube boilers and quadruple-expansion engines in cargo steamers on the Great Lakes, and has proved the potency of these factors by the great success with which large cargoes are handled in these waters.

In 1896, in order to facilitate general operation and render the drum fittings more accessible, the boiler was reversed in its relation to the fire room, or stoked from the opposite end. The firing doors were placed under the cross box forming the mud drum, or blow-off connection, the location of the steam and water drum being at the front of the boiler, immediately overhead. At the same time the economizer previously located in the up-take was abandoned, and its equivalent heating surface added to that in the boiler; the cost of up-keep in a marine boiler economizer, due to its inaccessible situation and essential piping, valves, etc., amounting to more than the advantages derived from its use.

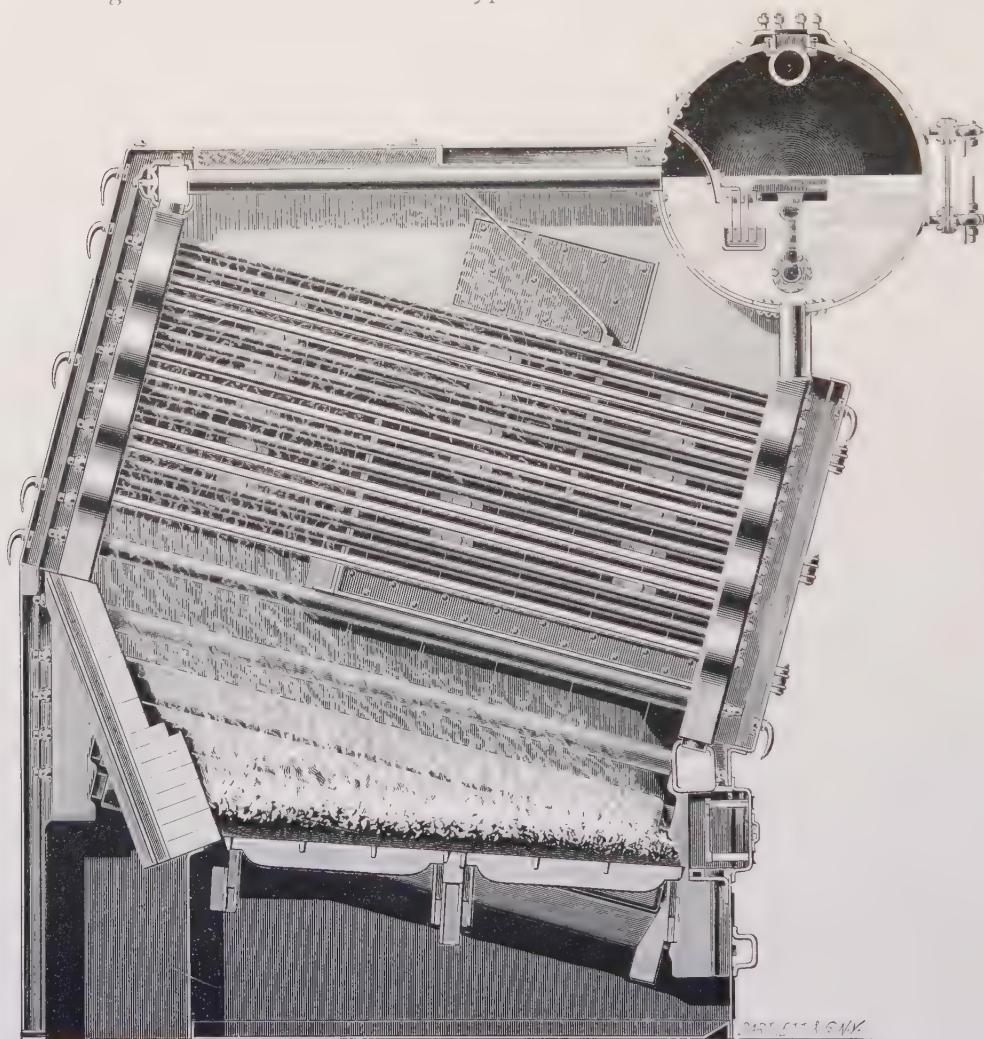
In 1899 this design was further improved by the use



BABCOCK & WILCOX, 1896
PATENTED

of longer tubes, increasing the length of the furnace, and by a system of vertical baffles, in connection with a roof of light fire tile placed on the lower row of tubes. This arrangement of heating surface reduced the height of the boiler, increased the furnace capacity and permitted thorough dusting of the tubes without opening the tube doors at the front or rear.

The first boilers constructed on this plan were built for the U. S. S. "Alert," and installed in that ship at Mare Island Navy Yard, California. Hence the design is known as the "Alert" type.



BABCOCK & WILCOX "ALERT" TYPE MARINE BOILER, 1899—PATENTED

REQUIREMENTS OF A MARINE WATER-TUBE BOILER



III. Service of a marine water-tube boiler demands the following essential features:

All materials of construction should be of the best.

All joints should be absolutely steam-tight.

All parts should be easy to inspect.

All joints should be reduced to a minimum.

All parts should be accessible for cleaning and repair.

In the Babcock & Wilcox marine boiler, all pressure parts are constructed entirely of *forged steel*—not a pound of cast-iron, cast-steel or malleable cast-iron being subjected to pressure. In the manufacture of the forged open-joint steel headers which connect the tube ends, The Babcock & Wilcox Company spare no expense, as they well know that no watertube boiler would ever be a successful competitor with the Scotch type unless built entirely of the same trustworthy material, *forged steel*.

Straight tubes that can be purchased in the open market are another necessity. The watertube boiler can then be retubed with the same facility and ease as the Scotch, as each tube can be withdrawn and replaced through its own tube hole, no row of tubes being destroyed in order to replace a new tube, or a tube bent to an exact curvature in a special tube-bending machine before it can be inserted into the boiler.

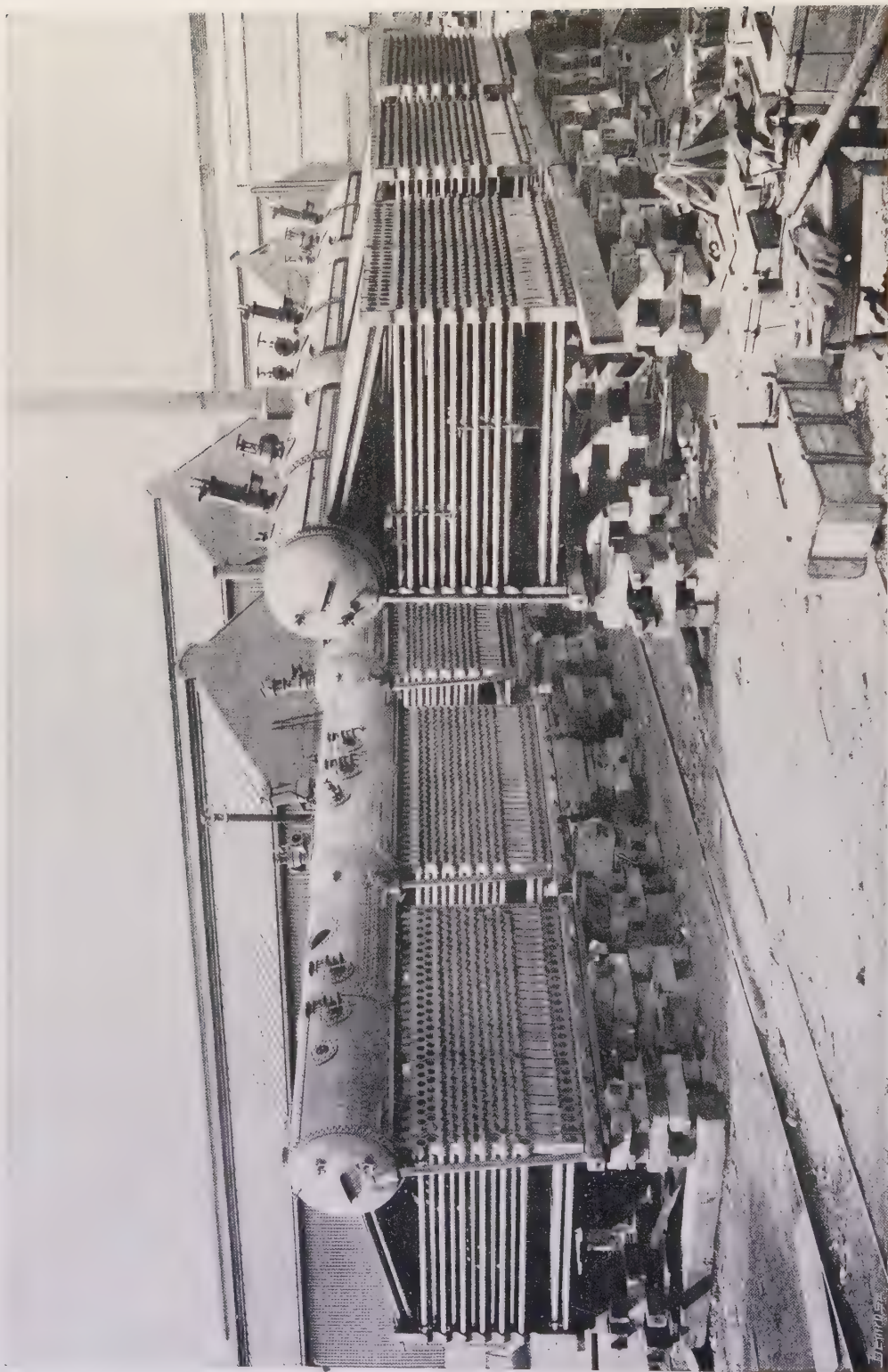
By the use of the expanded joint, The Babcock & Wilcox Company place in the hands of engineers a joint with which they are perfectly familiar; the old roller expander and taper pin being the only tools required to make tight any connection in the boiler, special threads and coned joints, so difficult to keep tight under the most favorable conditions, being entirely avoided.

As the furnace sides are encased with forged-steel boxes of square section, through which the circulation passes, there is no need of brick work, which adds weight and is expensive to renew. The only brick wall in use, therefore, is that common to all boilers, whether stationary or marine—the regulation bridge wall at the rear of the grate.

Lastly, a boiler to meet the requirements of everyday service, in all kinds of vessels, must be provided with facilities for keeping the exterior of the tubes free from sooty deposits, and should have a sufficient number of doors located in the casing to enable a thorough inspection of its interior.



FORGED-STEEL HEADER AND
FITTINGS—PATENTED



PRESSURE PARTS OF SIX BOILERS FOR SEA-GOING DREDGER "SAMSON"—PATENTED
ARMSTRONG, WHITWORTH & Co.—WALLSEND SHIP YARD—NEWCASTLE-ON-TYNE

DESCRIPTION OF THE BABCOCK & WILCOX BOILER



THE construction of the Babcock & Wilcox marine boiler embodies the same well-known principles as the successful land or stationary type; freedom of circulation, and economy when forcing, being important factors of both designs.

The tubes forming the heating surface are divided into vertical sections and, to insure a continuous circulation in one direction, are placed on an inclination of 15 degrees with the horizontal.

By distributing the surface into sectional elements, all danger from unequal expansion due to raising steam quickly, or sudden cooling, is at once overcome.

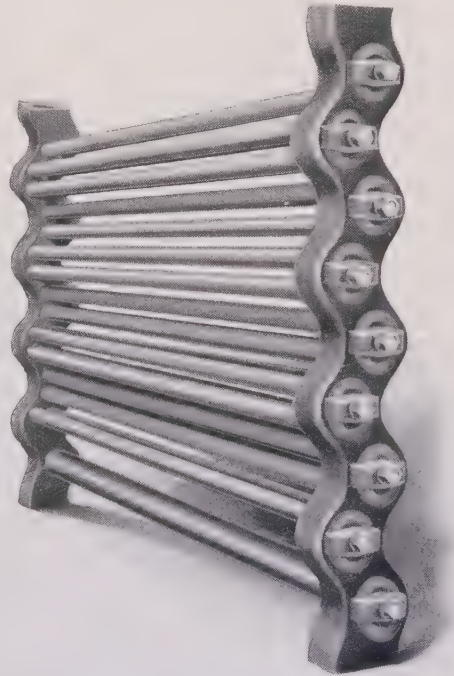
Each section is made up of a series of straight tubes expanded at their ends into corrugated wrought-steel boxes known as headers. As the headers are staggered, the tubes are so disposed that lanes for the sudden escape of the products of combustion are prevented. The hot gases are therefore completely broken up in their passage across the heating surface.

The side sections are continued down to the level of the grate, the tubes being replaced by forged steel boxes of 6-inch square section at the furnace sides. These boxes are located one above the other on the same angle as the tubes; they take the place of brick work; ensure a cool side casing; prevent the adherence of clinkers, and are of sufficient thickness to withstand the wear and tear of the fire tools.

Extending across the front of the boiler and connected to the upper ends of the headers by 4-inch tubes is a horizontal steam and water drum of ample dimensions.

As the upper ends of the rear headers are also connected to this drum by horizontal 4-inch tubes, each section is provided with an entirely independent inlet and outlet for water and steam.

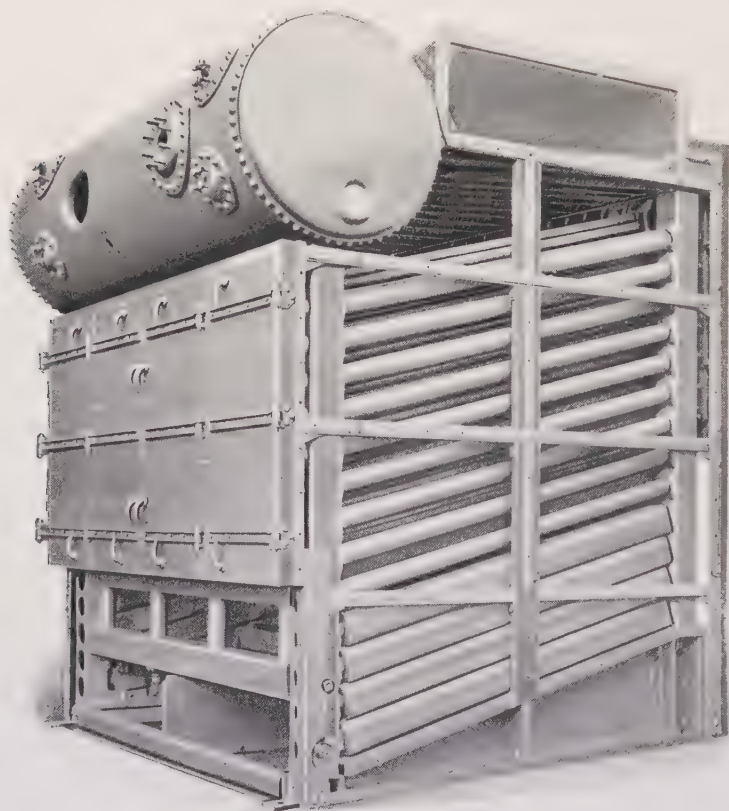
Placed across the bottom of the front header ends and connected thereto by similar 4-inch tubes, is a forged steel box of 6-inch square section. This box, situated at the lowest corner of the bank of tubes,



FORGED STEEL SECTION—PATENTED

forms a blow-off connection or mud drum through which the boiler may be completely drained.

The circulation of the water is as follows: Heat being applied to the inclined tubes and vapor formed, the water and steam rises to the high end and flows through the up-take headers and horizontal return tubes to the steam



FOUNDATION AND STRUCTURAL IRON OF CASING OF BABCOCK
& WILCOX MARINE BOILER—PATENTED

and water drum, the path of both water and steam being short and direct; the water evaporated in the tubes and that carried along by the currents induced by the steam bubbles being replaced by water flowing directly from the bottom of the drum downward through the front headers, or down-takes, and into the tubes, part of this water to be in turn evaporated.

Upon entering the drum the steam and circulating water are directed against a baffle plate, which causes the water to be thrown downward, while the steam separates and passes around the ends of the baffle plate to the steam space, from which it is conducted by a perforated dry pipe to the stop valve. By a roof of light fire tile, supported upon the lower tubes and extending part way over the furnace, the gases evolved from fresh fuel are compelled to flow toward the rear of the boiler, passing over an incandescent bed of coals and under the hot tile roof.

As the furnace increases in height approaching the bridge wall, the gases have both space and time in which to thoroughly mix and burn before entering the bank of tubes forming the heating surface. By this arrangement a high furnace temperature is established, which is acknowledged by all authorities to be the essential requirement of boiler economy.

The circuitous route which the gases are compelled to follow, in crossing the heating surface three times before exit, causes them to impart to the tubes the greatest possible amount of heat.

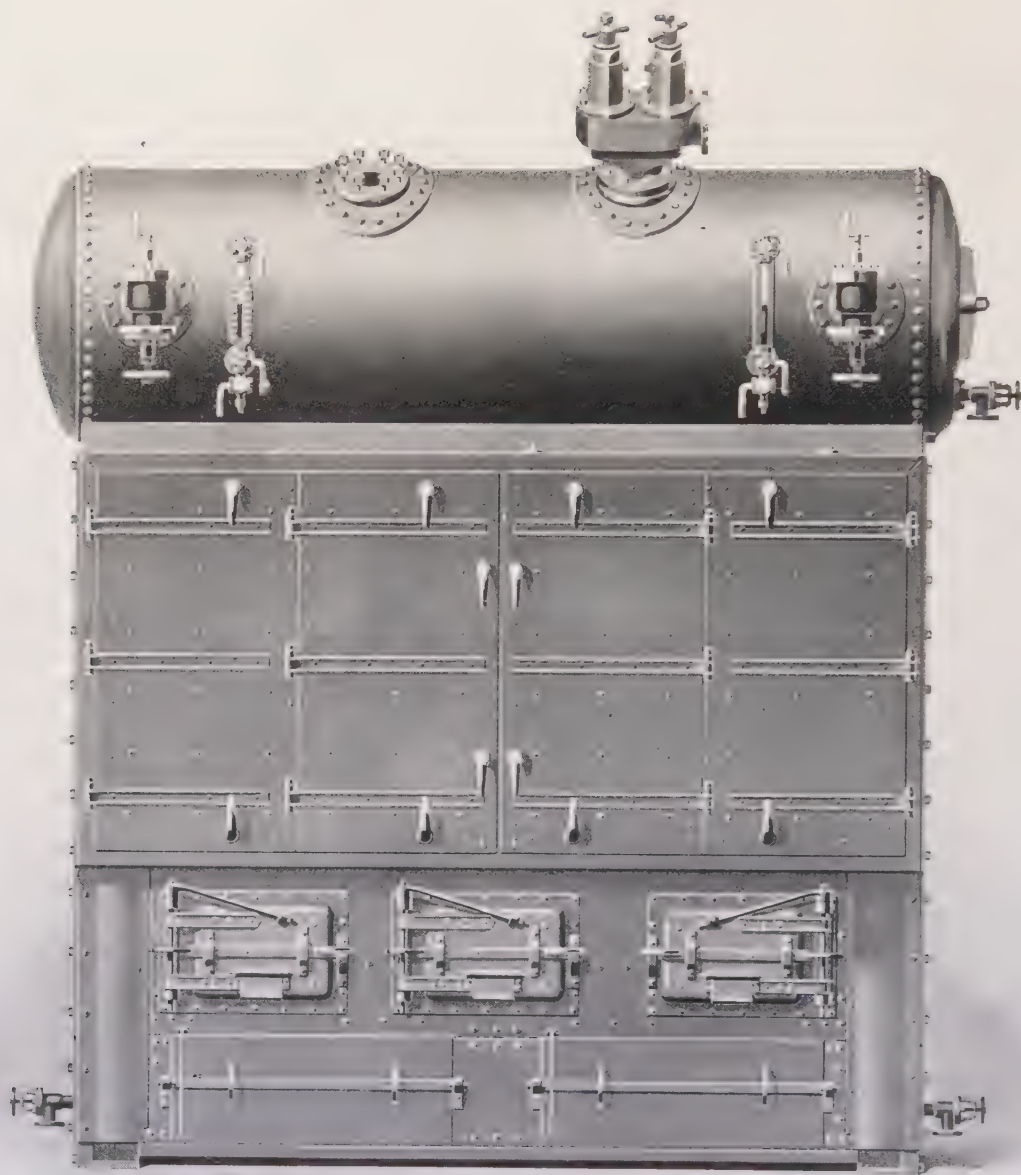
The distance traveled by the products of combustion in contact with the heating surface is about sixteen feet, hence good economy is maintained with high rates of combustion, and a low up-take temperature assured; the interval for the absorption of heat, so necessary for economy, being longer than in any other type of marine water-tube boiler. The temperature of the gases, taken at different places in their path to the funnel, will be found under "Tests of Babcock & Wilcox Marine Boilers."

All tubes are constructed of seamless steel and are extra heavy. Opposite the end of each tube is an opening, or hand hole, in the header, through which the tube may be examined, cleaned, plugged or renewed; each hand hole, of 4-inch diameter, being closed by a forged-steel plate into which is riveted a 1-inch stud. This plate is faced, and is drawn to a faced seat by a forged-steel bridge and nut, the joint being made on the inside of the header, by means of a thin gasket.

Should a tube be found defective, from whatever cause, it may be renewed or temporarily plugged, as both ends are accessible. All necessary repairs can be made by the ship's staff. The only tools required are a ripping chisel and an ordinary expander, the operation of which is familiar to every engineer.

The placing of the steam and water drum horizontal with its center on the water line of the boiler, provides a large body of water where it is most needed, and where changes in the volume of water carried least affect the levels in the gauge glasses.

The location of the drum at the front of the boiler renders all valves and fittings accessible and tends to shorten steam pipe connections. Main stop and safety valves, stop and feed check valves for both main and auxiliary feeds, and water glasses, are flanged directly to nozzles provided with counter-



FRONT VIEW—BABCOCK & WILCOX BOILER
SHOWING DRUM FITTINGS—PATENTED

bored seats and riveted to the drum shell or heads. The longitudinal seams are butted and strapped, and have from four to six rows of rivets, as the steam pressure requires. Butt straps are curved to proper radius in a hydraulic press.

The rivet holes are drilled after the rolled plates are assembled; the butt



straps are then removed from the drum plates and all burrs cleaned off. The rivets are driven by hydraulic pressure and held until cool.

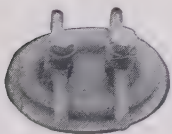
The drum heads are formed in a single heat, by hydraulic pressure, to a spherical surface whose radius is equal to the diameter of the shell. The man hole is flanged in the shell plate, or drum head, with a stiffening ring of



FORGED-STEEL DRUM HEAD

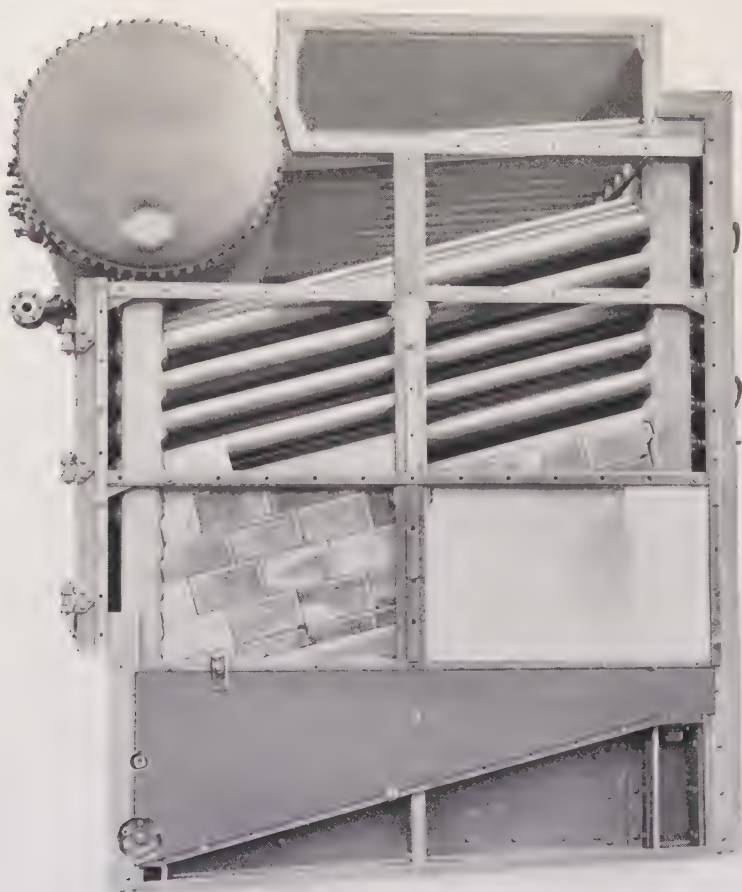
sufficient thickness to form, with the edge of the plate, a seat for the man hole gasket one inch wide. The man hole plates are 11 x 15 inches, and are faced to a true oval to fit the man hole.

Surrounding the pressure parts, and firmly bolted to the foundation, is a structural iron framing to which the casing plates are fastened.



The spaces between the side tubes are filled with light fire tiles made of highly refractory fire clay. Against these are placed asbestos mill-board and magnesia block covering. On the outside, firmly holding the non-conducting materials in position, are the casing plates, which are clamped to the structural framing by butt straps. This method of fastening allows of easy removal, and on replacing makes an air-tight joint without the use of additional

packing. The efficiency of the casing is demonstrated by the fact that the hand can be held upon the side of the boiler, when steaming, without discomfort, and the stoke hold is always cool.



CONSTRUCTION OF SIDE CASING—PATENTED

Hinged to the framing at the front and rear of the boiler are large doors, giving access to the hand-hole plates covering the tube ends.

Ample means are provided for blowing the soot from the exterior of the tubes. A steam lance may be inserted through small dusting doors empaneled in the side casing, as shown on the opposite page, and communicating with the spaces between the rows of tubes. Each opening is covered by a shutter sliding

vertically, which can be opened and shut by the lance. As the seat for this shutter is beveled, it tends on falling to wedge itself into position, thereby making an air-tight joint.

As all cleaning of soot from the exterior of the tubes is performed from the sides, the continuous steaming of the boiler and coaling of the grates by the stokers are not in any way hindered.



DUSTING DOOR—PATENTED



S. S. "ZENITH CITY"

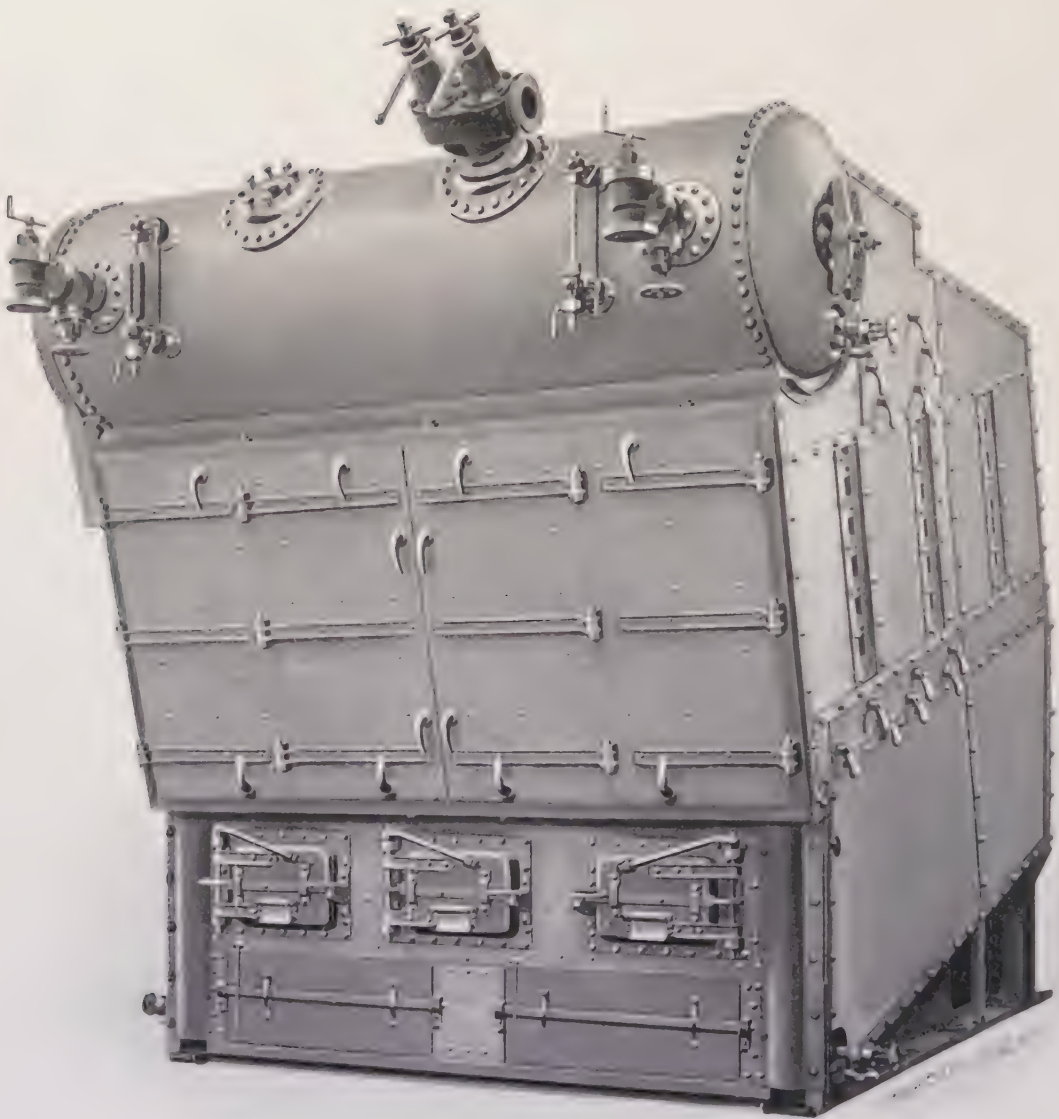
OWNERS: ZENITH TRANSIT CO. BARCOCK & WILCOX BOILERS, 2000 INDICATED HORSE-POWER

PRINCIPAL ADVANTAGES AND SALIENT POINTS



OLLOWING are some of the advantages obtained by using the Babcock & Wilcox marine boiler :

- 1st. *Reduction in weight for high steam pressure*, the weight being 25 pounds per square foot of heating surface for 250 pounds pressure, against 75 pounds per square foot in Scotch boilers for 175 pounds pressure.
- 2d. *Ability to raise steam quickly*, thus avoiding unnecessary delay to ship and cargo, which means money to the owners.
- 3d. *Reduction of space occupied and increased furnace capacity*.
- 4th. *The tubes are straight*, therefore they can be cleaned, inside and out, and examined without entering the boiler.
- 5th. *Absolutely free circulation*, allowing any amount of forcing of which the fireman is capable.
- 6th. *Water sides to furnace*, preventing serious radiation, occasioning a cooler fire room, and avoiding clinkering of furnace sides and repair to brick work.
- 7th. *Absence of automatic devices* of all kinds, that are continually getting out of order and giving trouble, such as feed regulators, reducing valves, steam separators, etc.
- 8th. *Steady water level*.—On account of the body of water carried in the steam and water drum at the water line, and the freedom of circulation, sudden fluctuations in the water level are prevented.
- 9th. *Steam space sufficient to obtain dry steam*, without the necessity of expanding from a higher to a lower pressure in order to evaporate the water in the steam.
- 10th. *Increased ratio of heating to grate surface*, thereby materially improving the economy.
- 11th. *Ability to clean, renew or plug a tube*, through a hand hole of sufficient size opposite the end of same, without removing any other tube or pressure part, or cooling down the boiler other than by blowing off the pressure.
- 12th. *All joints exposed to products of combustion are expanded into bored holes*, no screwed fittings being used.
- 13th. *Boilers of large units can be employed*, thus doing away with an increased number of small boilers, multiplicity of fittings and additional apparatus.



ONE OF FOUR BABCOCK & WILCOX BOILERS
BUILT FOR U. S. S. "WYOMING"—PATENTED

ADMIRAL MELVILLE ON WATER-TUBE BOILERS *



At the present day it would be hard to find any design for the machinery of new naval vessels which does not include water-tube boilers. The demands upon the engineer for great power on small weight, in order to secure the higher speeds for all classes of vessels which are now common, have practically ruled out the cylindrical boiler on account of its weight and inability to carry the high pressures needed.

"The tactical importance of water-tube boilers is also being thoroughly recognized, and has been emphasized by the conditions which obtained in our blockade of Santiago and the great victory of July 3rd. It was necessary for a long period that our ships should be ready to develop maximum power at a few minutes' notice, and with cylindrical boilers this involved keeping all the boilers under steam, with heavily banked fires and an attendant large consumption of coal. Water-tube boilers of the proper kind, which admit of the rapid raising of steam with safety, remove this difficulty and give the commanding officer a more complete control of his fighting machine.

"Without going at length into the other advantages of water-tube boilers, which have been published repeatedly, it may be added that one very striking advantage for war vessels is that the boilers can be replaced or practically rebuilt without disturbing the decks, all parts being small enough to pass through permanent openings. This was the case in the 'Monterey,' and was strikingly illustrated this summer in the case of the 'Canonicus,' 'Manhattan' and 'Mahopac,' where it would have been impossible to use any but water-tube boilers without practically rebuilding portions of the hull (see page 113)."

Referring to the causes for the adoption of water-tube boilers in the U. S. Navy, Admiral Melville says:

"The task I have set myself to-day is no mean one. I desire to show that the decision to use nothing but water-tube boilers in our future war vessels is a step in advance, and that it is a natural step towards the evolution of the perfect fighting machine. I desire to show that it is no radical change, and that it does not involve the use of anything but a tried, successful and reliable apparatus that gives us positive and great advantages over the character of boilers heretofore generally used. I desire not to minimize the disadvantages following this change, but to show that these disadvantages are not only not insurmountable, but, for war ships, they have already been overcome.

"Water-tube boilers have advantages and I have never been blind to them. Two years ago I stated that their disadvantages had been sufficiently removed to justify their use on our war ships. Now I consider that the value of their advantages has been sufficiently developed to necessitate their use if we do not wish to be left behind in naval design.

* Extracts from annual reports, etc., of Admiral Geo. W. Melville, Engineer-in-chief, U. S. Navy.



U. S. S. "CHICAGO"

UNITED STATES NAVY. BABCOCK & WILCOX BOILERS, 5000 INDICATED HORSE-POWER

“The ‘Chicago’ has several Babcock & Wilcox boilers, and these have so far worked in a thoroughly satisfactory manner, no failure being reported under any circumstances.

“The ‘Annapolis’ is also equipped with Babcock & Wilcox boilers, and here, as on the ‘Marietta’, these boilers have been thoroughly successful. Indeed, a former chief engineer of the ‘Annapolis’ has stated to me that the boilers of that ship were easier to manage in use, and easier to maintain in a state of high efficiency than are cylindrical boilers.

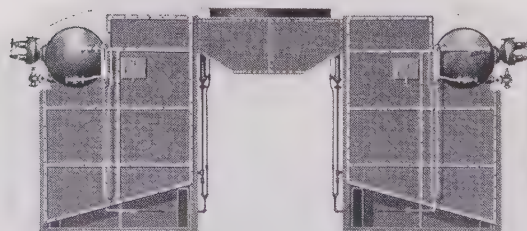
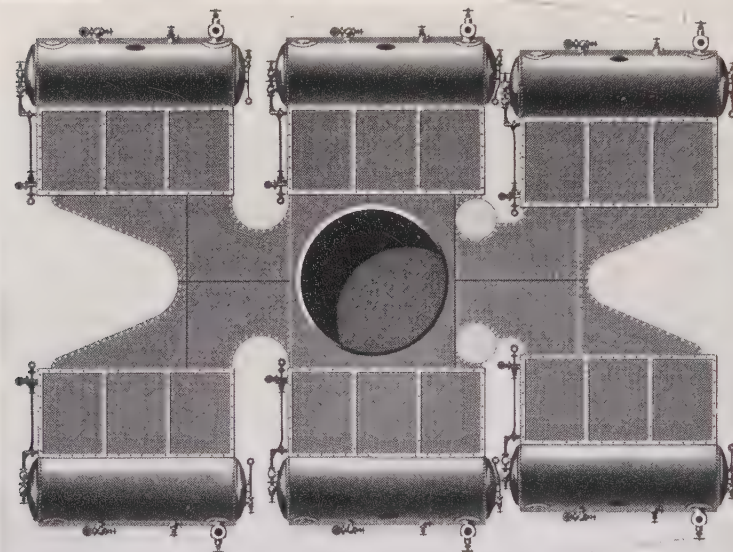
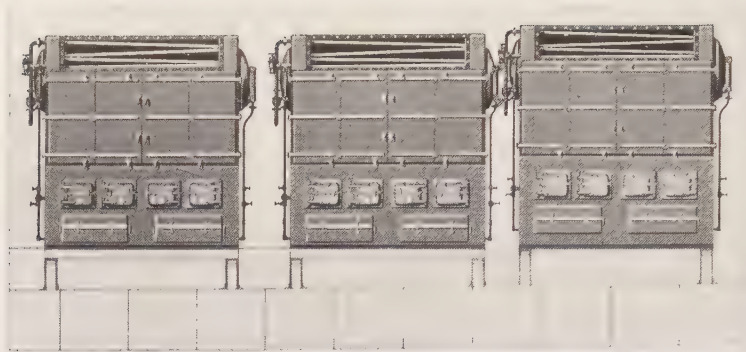
“The following table shows the relative economy of cylindrical and water-tube boilers :

	BABCOCK & WILCOX		SINGLE-ENDED CYLINDRICAL			
	Annapolis	Marietta	Newport	Princeton	Vicksburg	Wheeling
Number of boilers	2	2	2	2	2	2
Displacement, tons	1000	1000	1000	1000	1000	1000
Knots per ton of coal at most economical speed	26.38	22.27	18.0	19.6	21.25	16.6
Number of screws	1	2	1	1	1	2
Grate surface, square feet . . .	98	94	78	78	78	60
Heating surface, square feet . .	3620	3664	2524	2524	2524	2508

“The increased grate surface we have required with water-tube boilers will be a positive advantage to our ships’ steaming qualities. I consider that sustained sea speed depends largely upon the grate surface. Heating surface, of course, must be provided, but I should prefer an excess of grate surface to an exceedingly high rate of heating surface to grate.

“Up to this time we have had no trouble from salt water or grease in water-tube boilers. Indeed, we could hardly be more troubled by salt water with this type of boiler than we have been with cylindrical boilers. We suffered severely in our short war with Spain from dropped furnaces in cylindrical boilers. I do not think that a properly designed water-tube boiler will give more trouble from the use of impure water, such as sometimes we have at sea, than any other boiler. I do not think these tubes more liable than furnaces to fail from a deposit of scale.

“The fact that water-tube boilers raise steam quickly is of the greatest advantage. I have stated elsewhere that I consider the battle of Santiago to have developed the necessity of the use of water-tube boilers whether it taught us anything else or not. It would have been of the greatest advantage to have had, during the blockade of Santiago, boilers capable of raising steam in less than half an hour. Coal need not have been used to keep all the boilers under steam all the time. The ‘Massachusetts’ might have shared in the glories of the fight if she had been fitted with water-tube boilers. The ‘Indiana’ would have kept up with the ‘Oregon’ and the ‘Texas.’ The ‘New York’ would have developed at least three knots



ARRANGEMENT OF BABCOCK & WILCOX BOILERS IN U. S. S. "CHICAGO"

more speed and the Navy would have been spared a controversy. I think the 'Colon' would not have gotten as far away as she did. But we did not have the water-tube boilers.

"The higher pressures possible with water-tube boilers give us smaller and safer steam pipes and better valves. It decreases the size of the fittings and the difficulty of tracing the labyrinth of a ship's piping.

"The introduction of compound engines forced us to use cylindrical boilers. In the same way the use of quadruple-expansion engines necessitates, for economy, the use of water-tube boilers.

"I HAVE ALWAYS OPPOSED THE USE OF BOILERS CONTAINING SCREW JOINTS IN CONTACT WITH THE FIRE, AND HAVE ATTEMPTED TO SECURE BOILERS HAVING NO CAST METAL IN THE PRESSURE PARTS. CAST-STEEL IS NOT YET GOOD ENOUGH TO PUT BETWEEN 300 POUNDS OF STEAM AND OUR FIREMEN. I believe in straight tubes as being easier of examination and repair than bent-tube boilers. I believe in large-tube boilers for the same reason and because the tubes are thicker and have more margin for corrosion. I believe in boilers having as few joints as possible. Water-tube boilers must have freedom of expansion of the various parts, and the simpler the boiler the better. It should not be necessary to introduce reducing valves between the boilers and the engines to secure a steady steam pressure at the latter, nor should it be necessary to have automatic feed arrangements to secure a steady water level in the boilers. To be successful a boiler must be easy of repair. Lightness is a natural attribute of all water-tube boilers, but it is not wise to go too far in this direction. The ratio of grate surface to fire surface occupied for the complete boiler plant must be as large as possible. The units should be large, the grates short and not too wide. The passage of gases through the tubes should be sufficiently long to ensure economy. These gases should be well mixed before entering the spaces between the tubes, for the same reason, and to prevent smoke. The circulation of the water in the boiler must be free. Tubes should not be too long and the fire rooms must always be sufficiently wide to provide for free withdrawal."

With special reference to the performance of the "Annapolis" and "Marietta" during the war, the Admiral further writes :

"The 'Annapolis' was commissioned July 20th, 1897, and the 'Marietta' Sept. 1st, 1897. Before the outbreak of the war the 'Annapolis' was employed to prevent filibustering, and the 'Marietta' had been engaged in ordinary cruising in the Pacific.

"The 'Marietta' made a trip almost as long as that of the 'Oregon,' as she left San Jose de Guatemala on March 16th, and arrived at Key West on June 4th, having been under steam continuously for nearly three months and having covered a distance of over 13,000 miles at an average speed of 9.2 knots. As this came after the vessel had already been in service for nearly a year, the record is very creditable.

"The special point to be noted in connection with both vessels is that after more than a year's commission, during which time they have steamed thousands of miles,



U. S. MONITOR "CANONICUS"
BARBOCK & WILCOX BOILERS, 1500 INDICATED HORSE-POWER

the boilers of both vessels are in excellent condition and ready for any service. In other words, they have withstood the test of long periods of actual cruising just as well as cylindrical boilers, and with as few mishaps as any and much fewer than some. In the case of the 'Marietta,' all that was called for at the end of her long trip were a few fire bricks, and the 'Annapolis' needed nothing."

T.B.S.--W.D.L.

IN REPLY REFER TO NO. 29181

NAVY DEPARTMENT,
BUREAU OF SUPPLIES AND ACCOUNTS,
WASHINGTON, D. C.

June 10, 1898

Gentlemen:-

1. Please forward to the Commanding Officer, U.S.S. "MARIETTA", Key West, Fla., 8 fire bricks, 4 rights and 4 lefts, #R, 3440, Babcock & Wilcox boiler, to replace broken bricks between furnace doors.

2. Your bill for these articles should be sent to the same officer and should refer to Steam Engineering Requisition, dated June 1, 1898.

Respectfully,

E. A. Stearns
Paymaster General, U. S. N.
W. S. V.

The Babcock & Wilcox Co.,
29 Cortlandt St.,
New York, N.Y.

JUN 21 1898



U. S. GUNBOAT "MARIETTA," WHICH ACCOMPANIED THE BATTLE SHIP "OREGON" AROUND THE HORN

FITTED WITH BABCOCK & WILCOX BOILERS

U. S. GUNBOATS—"MARIETTA" AND "ANNAPOLIS"



THE following interesting account of the performance of the "Marietta" is from an official report to the Navy Department by Passed Assistant Engineer W. H. Chambers, U. S. N., the Chief Engineer:

"In her recent trip from San Francisco to Acapulco, Mexico, the U. S. Gunboat 'Marietta' showed what the new type of naval vessel can do in the matter of economy of coal.

"She left San Francisco on January 16th, and arrived at Acapulco January 25th, after a trip marked only by good weather and smooth seas. During the trip runs were made for periods of 48 hours each, the engine revolutions being maintained at as near a constant rate as possible, and a careful account kept of the distance run and the amount of coal burned during these times. Three different rates of revolutions of engines were taken, giving speeds of $10\frac{1}{2}$, $9\frac{1}{2}$ and $8\frac{1}{2}$ knots, respectively.

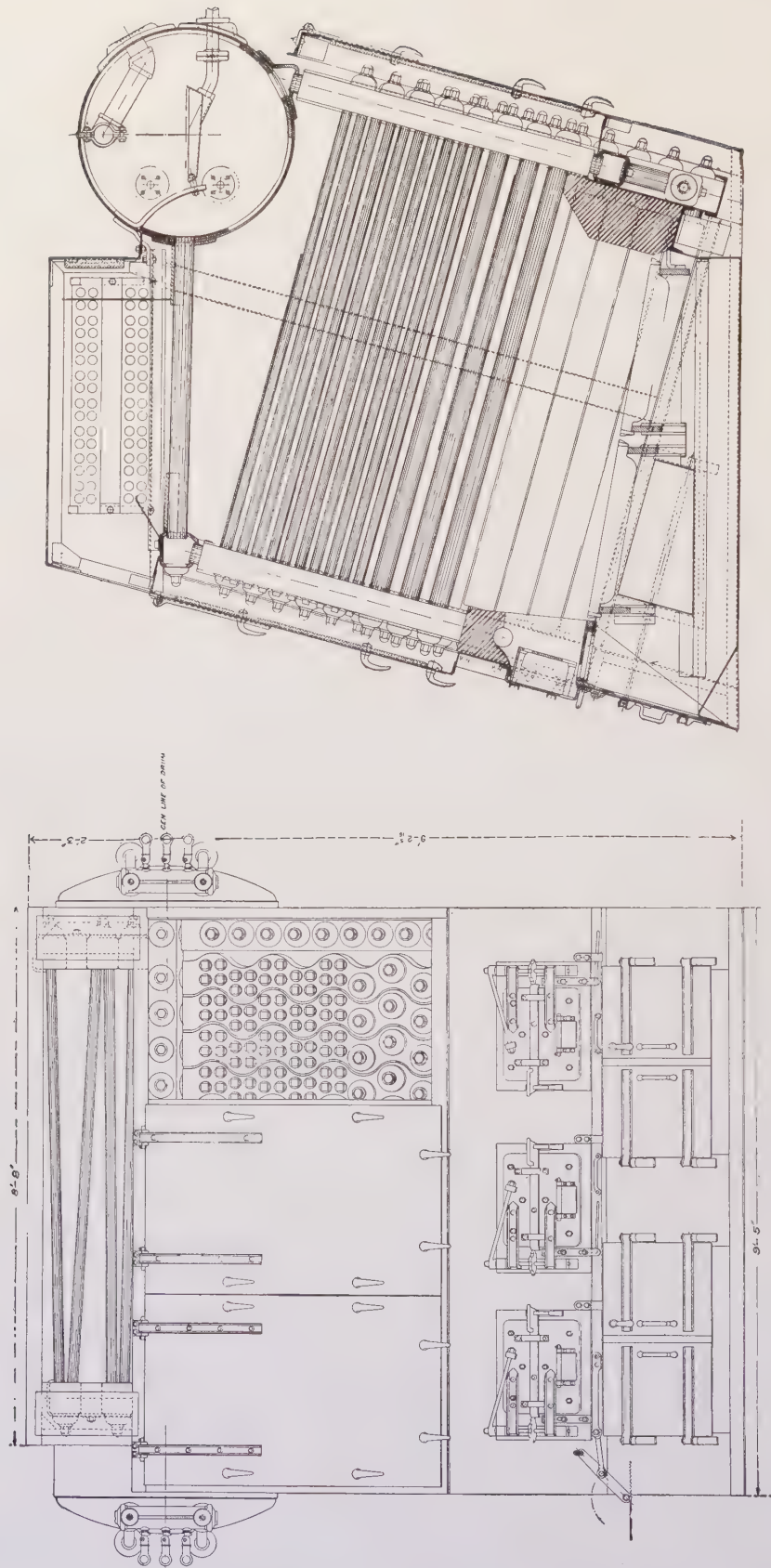
"At the $8\frac{1}{2}$ -knot speed the wonderfully small coal consumption of $6\frac{1}{2}$ tons a day was obtained. In other words, the 'Marietta' steamed 204 miles a day on only $6\frac{1}{2}$ tons of coal, or could go more than 7500 miles on her total coal supply.

"When it is remembered that this coal expenditure represents not only the steaming, but the electric lighting, ventilating, cooking and heating of the ship, it can be seen how economical this is for a vessel of 1000 tons displacement."

	I	2	3	4
Boilers in use	A and B	A and B	B	B
Duration in hours	47.97	63.75	47.63	35.35
Distance, patent log, knots	507.7	609.6	543.7	364.8
Mean speed, patent log, knots	10.58	9.56	9.53	8.57
Mean revolutions, main engine	181.1	160.5	160.0	140.3
Indicated horse-power, main and auxiliary machinery	549.5	371.2	360.0	273.8
Indicated horse-power, auxiliary machinery (estimate)	18.0	16.0	17.0	17.0
Indicated horse-power, main engines only	531.5	355.2	343.0	256.8
Coal for all purposes for run, tons	26.60	27.36	17.90	9.46
Coal for auxiliary machinery, including evaporator, blowers and heating ship (estimate)	3.60	5.55	4.00	3.30
Coal for main engine for run	23.00	21.81	13.90	6.16
Coal for main engines for day	11.50	8.20	7.00	4.15
Coal for main engines per indicated horse-power	2.02	2.16	1.91	1.52

Auxiliaries in use—Two main circulating pumps; one boiler feed pump; one dynamo; one F. & B. pump; steering engine; all constantly. 1—Heating ship. 2—Heating ship about half the time; evaporator 0.6 time. 3—Two ventilating blowers 0.5 time; evaporator 0.5 time. 4—Two ventilating blowers 0.5 time; evaporator 0.5 time.

The "Marietta" is a composite gunboat, 174 feet in length on the water line, 34 feet breadth of beam, 12 feet draft and of 1000 tons displacement. The machinery installation consists of twin-screw vertical triple-expansion engines, with cylinders 12, 18 and 28 inches in diameter by 18 inches stroke. The Babcock & Wilcox boilers are 11 feet 6 inches in length and 9 feet 6 inches in width, with a height over all of 11 feet. The grate surface aggregates 94 square feet and the total heating surface 3620 square feet. There are 57



FRONT AND SIDE ELEVATIONS OF BOILERS OF U. S. S. "MARIETTA" AND "ANNAPOLIS"—PATENTED

4-inch and 260 2-inch tubes in boiler and 64 2-inch tubes in heater. The boiler tubes are 7 feet 6 inches in length, while the tubes in the heater have a length of 6 feet 8 inches. The total weight of boilers, ash pans, and all fittings (dry) is 94,016 pounds, while the aggregate weight (with water) of boiler, ash pans and all fittings is 112,016 pounds.

TRIAL OF THE "ANNAPOLIS"

The trial of the "Annapolis," the first finished of the six composite gunboats ordered by the Government in the early part of 1896, took place on Long Island Sound, April 22, 1897. The "Annapolis" was constructed at Elizabethport, N. J., and was the first vessel of large type in the United States Navy to be equipped with all water-tube boilers. She is 204 feet long, 36 feet wide and 22 feet 3½ inches deep. Her displacement is 1090 tons on a draft of 12 feet. The Bureau of Steam Engineering has heretofore preferred the use of water-tube boilers in connection with those of the Scotch type; but, after repeated investigations and at the request of the constructors, Babcock & Wilcox all forged-steel boilers were adopted for both the "Annapolis" and "Marietta."

The boilers in the "Annapolis" are built for a working pressure of 250 pounds to the square inch, there being two in number, supplying steam to a triple-expansion engine having cylinders 15, 24½ and 40 inches diameter, and a stroke of 28 inches. Specifications for the boilers called for a total of 3600 square feet of heating surface and 94 square feet of grate, giving a ratio of about 38 to 1, the contract speed to be 12 knots and indicated horse-power 800. From the performance of the boilers on the builder's trial it was shown that over 900 indicated horse-power could be developed under natural draft, although the funnel is very short. On the official trial, ash-pit draft was used, each boiler was supplied by air from independent Sturtevant fans, the average air pressure in the ash pit being limited to one inch of water.

TIME OVER 48-KNOT COURSE

Stake Boat	Knots	Time		Speed in Knots
		Minutes	Seconds	
Cactus	6	26	27	13.7
Markeeta	12	27	1	13.3
Iwana	18	27	18	13.2
Cutter	24	28	10	12.8
Leyden	30	28	17	12.7
Cutter	36	26	00	13.8
Iwana	42	25	49	14.0
Markeeta	48	25	2½	14.20
Cactus				

Average speed, 13.43 knots per hour. Maximum speed, 14.18 knots per hour. Minimum speed, 12.7 knots per hour.



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U. S. GUNBOAT "ANNAPOLIS"
FITTED WITH BARCOCK & WILCOX BOILERS

The maximum indicated horse-power developed by the main engine was 1400, the average being 1320 at 147 revolutions per minute. The collective indicated horse-power will average about 1360. The maximum speed was 14.2 knots and the minimum 12.7. This low figure occurred through the pilot losing sight of the Leyden's cutter on the first 6-mile leg of the return course. When the end of the "four hours at full speed" test was reached the helm was put hard to port and to starboard without reducing the speed, and the little vessel made circles with a diameter of 400 feet. In turning she heeled only 3.5 degrees.

OFFICIAL TRIAL—FIRE-ROOM DATA

Time A. M.	Boiler Pressure Pounds	Draft Pressure in Ash Pit, Inches		Remarks
		Port	Starboard	
9:00	220	.78	.68	
9:15	220	.85	1.10	
9:30	230	1.10	.65	
10:00	223	.92	.70	
10:15	225	.55	.71	
10:30	223	.82	.82	
10:45	225	.98	.85	
10:49	...	...	...	Passed 24-knot stake boat and turned for home
11:00	223	.92	.91	
11:15	218	.76	1.15	
11:30	232	.65	1.10	
11:45	222	.91	.80	
12:00	224	1.00	.80	
12:15	222	1.12	1.20	
12:30	232	1.00	1.00	Indicated horse-power, main engine, 1319
12:45	234	1.20	1.20	
12:47	240	...	...	Full speed until 1 P. M., to complete 4-hour trial
Average	226	.90	.91	

Before leaving the "Annapolis," Commodore Dewey (who became the famous hero at Manila, now Admiral Dewey), said that he was going to send this telegram to the Secretary of the Navy: "'Annapolis' trial most satisfactory; speed 13.43." "It is not customary and hardly proper," said the Commodore, "to use adjectives in such despatches, but really, this time it cannot be helped. She deserves them."—*Marine Review*.

WAR SERVICE OF THE "ANNAPOLIS"

By Lieut. G. R. Salisbury, United States Navy, Chief Engineer United States Ship "Annapolis."

The little gunboat "Annapolis" has, since the breaking out of the war with Spain, been most actively engaged.

During that time the service performed consisted in convoying the "Fern" with ammunition from Tampa to Key West. Three weeks on the blockade in front of Havana, where she took part in the engagement with the cruiser "Conde Venedito" and two gunboats that attempted to run the blockade, but owing to the prompt action of the blockading fleet, did not venture beyond the range of Morro's guns. The "Annapolis" was instrumental in the capture of the French steamer "Lafayette" and barque "Santiago Apostol;" the former being released upon arrival at Key West on application of the French Ambassador. From service on the blockade, Captain

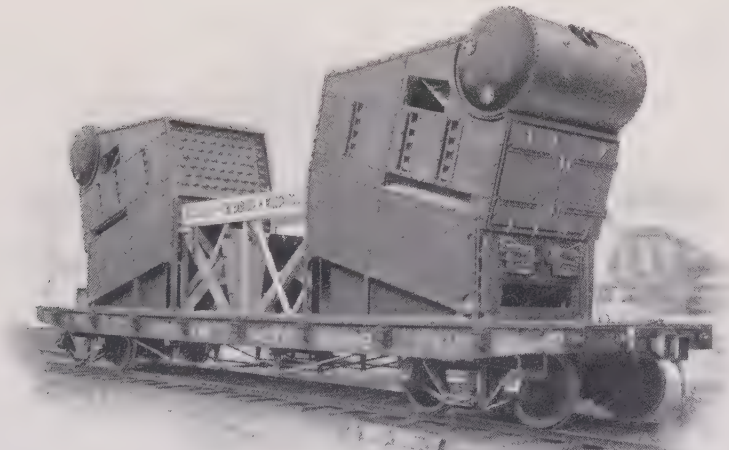


Hunker was ordered to Port Tampa, to take charge of, and arrange for, convoying the Army of General Shafter to Santiago de Cuba. The fleet thus formed sailed from Tampa on June 14th, consisting of thirty-eight steamers loaded with troops and five gunboats. The sight presented as they steamed out of Tampa Bay was truly magnificent. Upon arrival at Santiago, six days later, the "Annapolis" was detailed to take part in the bombardment of Siboney; the object being to distract the attention of the Spanish while United States troops were disembarking at Daiquiri. Siboney is four miles west of Daiquiri, and it transpired afterwards that a detachment of troops dispersed by the fire of the gunboats in front of Siboney was a portion of General Linares' army on its way to contest the landing of General Shafter. After several days in front of Siboney and Daiquiri the "Annapolis" was ordered to Guantanamo Bay, and for three weeks guarded the upper part of the bay against attack of several Spanish gunboats stationed at Caimanera. Guantanamo Bay was used as a naval base, and there were at that time several colliers, supply vessels, repair ships, torpedo boats, besides cruisers and battle ships, coming constantly for coal, provisions and repairs. Later the "Annapolis" was sent to Baracoa to intercept a vessel laden with

provisions for the Spanish forces stationed there; while near the town was fired upon by the fort. A short and spirited engagement followed in which the shore battery was silenced.

Returning to Guantanamo Bay the ship was ordered to proceed with the "Wasp" and "Leyden" to the capture of Nipe Bay, which was successfully accomplished, after running over mines placed in the channel, driving back troops stationed on heights above the entrance, and sinking the Spanish cruiser "Don Jorge Juan" and one gunboat. This exploit was similar to the capture of Manila Bay; it being necessary to pass over torpedoes that, happily, proved to be inoperative, though not known to be so at the time. From Nipe the "Annapolis" went to Puerto Rico and was the first vessel to enter the Port of Ponce, that had been selected by General Miles as landing place for his army. She was then dispatched on a cruise about the island in search of transports from the United States that had been ordered to assemble at other points, and to send them to Ponce. While on this mission she took part in the capture of Cape San Juan.

During the war the vessel steamed 8577 miles, and her engines have made more than six million revolutions. The machinery is in splendid condition, and there has never been a moment's delay on its account. The boilers have proved to be admirably adapted to war service, where it is necessary to change speed and steam pressure often and quickly. Not a leak was developed, and all machinery was kept at the highest point of efficiency by the men of the engineer's force, though called upon continually for watch and regular duties.



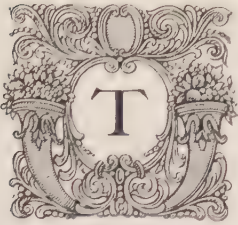
A 3500-MILE RAIL SHIPMENT FOR THE PACIFIC COAST



S. S. "NERO"

TONNAGE, 1083 TONS, GROSS; 697 TONS, NET. OWNERS: MESSRS. THOS. WILSON, SONS & CO., LTD., HULL
FITTED IN 1891 WITH BABCOCK & WILCOX BOILER, 500 INDICATED HORSE-POWER

COMMENTS ON THE "BATTLE OF THE BOILERS"



HERE is probably no legislative body in the world whose membership includes so many eminent shipbuilders and engineers as the British Parliament, and these experts have rendered the Empire a great service in carefully scanning the Navy estimates and studying the reports submitted by the Lords of the Admiralty. Projected naval legislation is therefore intelliĝently criticised before being enacted into law, for everything relating to the Navy possesses a special interest for the loyal Briton. It has been because such practical and loyal technical experts have scrutinized the Navy estimates that the material of the British Empire is so efficient, and when these men declare that the boiler question is now the paramount one in naval construction, the subject may be considered as one of importance to every nation that aspires to naval power.—*N. Y. Tribune*, Dec. 25, 1900.

From a recent speech of Hon. C. H. Wilson (Hull, W.), delivered in the House of Commons July 17th, 1900, we quote the following :

"I think I ought, having had more, perhaps, practical experience of the working of the water-tube boilers at sea than any other member of the House, to give to the House the results of that experience. . . . Take the experience of my own firm. To some extent we found the same faults with the old cylindrical boilers which the Admiralty did; and we have in the same way asked ourselves how these things could be remedied. Water-tube boilers were brought before us eight years ago, and one was put in the ship called 'Nero,' which has been continuously at work ever since. . . . In 1891 we got to work with the 'Nero,' and since then she has made 79 voyages, and run 165,965 knots. In 1895 we built the steamer called the 'Hero.'"

Commander Bethell (Yorkshire, E. R., Holderness): "Were these fitted with the Belleville boilers?"

Mr. C. H. Wilson: "No; they were fitted with Babcock & Wilcox water-tube boilers. The 'Hero' made 257 voyages out and home, that is to and from Hull to continental ports and back again, and ran 131,045 knots. In 1896 we took the old cylindrical boilers out of another of our steamers in the same way as we had done with the 'Nero,' and put water-tube boilers in her: and she has made 104 voyages, and run 106,293 knots. In 1897 we did the same thing with the 'Orlando,' which has made 68 voyages, and run 84,306 knots. In 1898 the old cylindrical boilers were taken out of the 'Rollo,' and water-tube boilers substituted, and she has made 49 voyages, and run 53,975 knots. In 1898 the 'Otto' was built for the short weekly continental trade, and was fitted with water-tube boilers. She has made 99 voyages, and run 51,894 knots. In the same year the 'Truro,' a new vessel, was fitted with water-tube boilers. She has made 94 voyages, and run 51,291 knots. In 1899 the cylindrical boilers were taken out of the 'Tasso,' and water-tube boilers put in. She has made 27 voyages, and run 44,046 knots. This steamer makes frequent voyages from Hull to the west coast of Norway and carries a great many of our friends backwards and forwards with perfect safety. Summing up the results of all these steamers, I find that they have made 800 voyages and run 700,000 knots, and



S. S. "TRURO"

225 FEET LONG, 32 FEET BEAM, 15.5 FEET DEEP MOULDED, DEAD WEIGHT CARRYING CAPACITY, 880 TONS. OWNERS: MESSRS. THOS. WILSON, SONS & CO., LTD., HULL. FITTED IN 1898 WITH TWO BABCOCK & WILCOX BOILERS, 1500 INDICATED HORSE-POWER

practically we have not experienced all the dangers and difficulties that have been predicted. I do not say that the water-tube boilers are perfect. As we go on we get more knowledge, the same as the Admiralty are getting; and we are now getting, I hope, nearer perfection. We have steamers running to America, and we are taking the cylindrical boilers out of one of them and putting in water-tube boilers. In a few weeks this steamer will be running a voyage out and home of 7000 miles, and that will give a very good test.* Taking the other side of the question, in 1895 we had Belleville boilers put into the 'Ohio,' but they were not satisfactory, and we took them out after runs of 111,000 knots to America and back. . . . Personally I feel convinced that the Admiralty will never go back again to the use of cylindrical boilers. I have heard it stated from the other side of the House, by the Hon. Mr. W. Allen, member for Gateshead, that there is no saving in the weight by the use of water-tube boilers. That is a great mistake. There is an enormous saving in weight. He omits altogether the enormous weight of the water in the cylindrical boilers as compared with that in the water-tube boilers; and it is self evident that there is a very great advantage, more especially in the Navy. But even in the case of the mercantile marine, as a practical ship owner, I think it is a great advantage. Take one of our smaller ships; there is a saving of some fifty tons of weight in boiler and water. And if that ship makes fifty trips from Hull to the Continent and back, that is 100 in all per annum. They could, by the use of water-tube boilers, carry 5000 tons more cargo."

The *Tribune* again states:

"This battle of the boilers has also been going on at Paris, Berlin, St. Petersburg and Washington, but the period has now been reached when, so far as each individual nation is concerned, a choice will have to be decided upon. Without going into technical details, it need only be said that the cylindrical boiler has had to give way on the war ship to the water-tube type. The questions of weight, space occupied and endurance have caused the change.

"The United States is therefore about to solve the boiler question, and in securing a type of American design the Navy is adopting one that can be relied upon in time of emergency, for if war should come, there would be thousands from shore who would understand its manipulation after a brief period of training."

Admiral Melville refers to this matter in his last report (1900), from which we quote the following paragraph:

"One point in particular will illustrate the extreme value of high professional criticism in design. Some years ago the Department was urged, with no little

* Extract from the *Pall Mall Gazette*, extra special edition, Nov. 8, 1900:

"*Editor Pall Mall Gazette:* Sir—We notice a paragraph in your issue of the 6th inst. referring to our steamship 'Martello,' in which you stated that this vessel burnt 448 tons more coal on her voyage since being fitted with water-tube boilers than she did previously with ordinary cylindrical boilers.

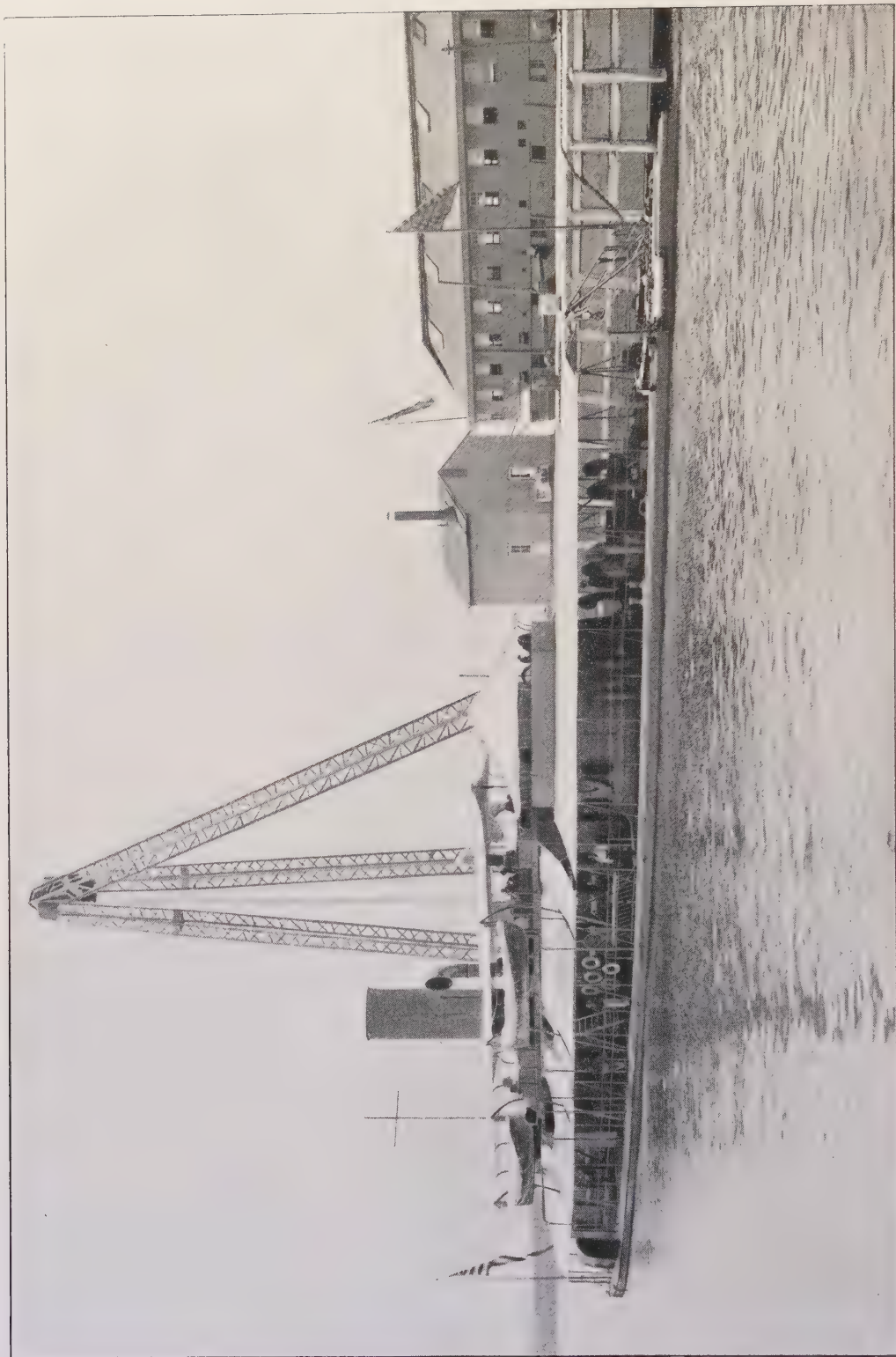
"This is quite incorrect; the coal consumption on her first voyage with water-tube boilers being 100 tons less than the average of three years with ordinary boilers, and the speed is 1.72 knots faster.

"We think, in courtesy to us, you should have given us the opportunity of verifying your figures before publishing them, which we shall at all times be pleased to do, and we should be much obliged by your letting us know how you got this most inaccurate information. The ship is now on her second voyage, and we have every reason to believe that the performance will be improved. We may add that nine of our steamers are now fitted with Babcock & Wilcox water-tube boilers.

"Yours, etc.,

"For THOMAS WILSON, SONS & CO., LTD.,

"Charles H. Wilson, M. P., *Chairman*."



U. S. MONITOR "MAHOPAC"
BARCOCK & WILCOX BOILERS, 1500 INDICATED HORSE-POWER

pressure, to adopt the Belleville water-tube boiler as a standard for the new ships. This Bureau opposed the innovation wholly upon a close examination of the designs, criticising the very defective features which in later years have made conspicuous the comparative inefficiency of this type over the purely straight-tube, non-screw-joint type for which I have given continuous and urgent preference. The Department is to be congratulated upon escape from this 'pressure' and upon the conservative approval it has given to the change in the boilers of naval ships. Instead of having been encumbered during the last war with ships powered with a type of boiler necessitating a specially trained force even for its safe operation, the most effective vessels had either retained the Scotch boiler or possessed the simple straight-tube Babcock & Wilcox boiler, and remained free from any real danger of becoming *hors du combat* by reason of lack of a completely experienced fire-room management, or the sudden failure of delicate or intricate special apparatus connected with the steam generators.

"In many other details, difficult to make clear without purely technical description, has the Bureau prevented the incorporation of faulty features in design and has advanced the proportional perfection of machinery."

Recently there appeared in the leading German marine periodical, *Schiffbau*, a semi-official article which summarizes the results of tests conducted at the Imperial Experimental Station at Charlottenburg. Referring to Babcock & Wilcox Marine Boilers, this summary says :

"This system of boilers is, besides, free from all complicated parts such as are found, above all, in the Belleville boilers. Stay bolts and braces are not required, and the tubes are entirely untrameled in their extension longitudinally ; so that leakages are hardly to be expected with fair workmanship. The circulation is simple throughout. Nickel gaskets and similar expensive joints are here unnecessary. The steam drum gives up its whole space for the reception of steam. The entire labyrinth of baffle plates, so characteristic of the Belleville boilers, and which so obstructs the passage of steam, is entirely omitted. It is therefore much easier to examine and to control the newly-produced steam as well as the steam drum itself. The Belleville boiler without a reducing valve is not feasible ; it requires a special feed pump ; a special feed-water regulation ; the burdensome water tending must be of the very best imaginable, and the fuel must be excellent. In actual practice, when the safety of the ship and the machinery are depending on such points, the many features that are required to make up such a system are well calculated to give rise to serious cares. The Babcock & Wilcox boiler, on the other hand, may be tended like any good cylindrical boiler ; their instalment requires no special arrangement, and even with a smoky coal fair results of efficiency have been obtained. These advantages develop themselves when the boilers are regarded from a mere technical standpoint. In quite a natural manner, therefore, one arrives at the conclusion that a trial with these boilers in our own Navy would be advisable, especially since the Babcock & Wilcox Company has works in Germany at Oberhausen.

"Furthermore, it may be reasonably supposed that this system will adapt itself readily to the constantly varying and progressing requirement of the naval service, because it is composed of simple parts. The number of advantages which this boiler has over others in many points, will be increased by progressive studies, so that it should receive greater consideration in our Navy as well as in our merchant marine."



H. M. S. "SHELDRAKE"
FITTED WITH FOUR BABCOCK & WILCOX BOILERS, 3500 INDICATED HORSE-POWER

H. M. S. "SHELDRAKE"—TESTS AND SEA TRIALS



THE "Sheldrake" is a torpedo gunboat of the "Salamander" class, with twin-screw triple-expansion engines of 3500 horse-power, collectively. Each engine has cylinders 22, 33 and 49 inches in diameter with a stroke of 21 inches.

There are two boiler compartments—divided by a water-tight bulkhead—two boilers in the forward compartment, and two in the after compartment. Each pair of boilers is placed back to back; each boiler having its own stoke hold. The boilers are fired fore and aft.

The total heating surface in each boiler is 2356 square feet, and the grate surface 63 square feet.

The boilers are composed of 19 sections of tubes, including side sections. The tubes throughout are of solid drawn steel, galvanized on the outside by the electro-deposition process in accordance with the usual Admiralty requirements. The tubes connecting the headers and cross boxes together are $1\frac{3}{8}$ inches in diameter—those between the headers are 7 feet 6 inches long, and those in the cross boxes 7 feet $4\frac{3}{4}$ inches. The up-take headers are connected to the steam and water drum by 4-inch tubes; 4-inch down-comer tubes are taken from each end of the steam and water drum, and connected to a wrought mud box, this box being provided with blow-off and drain valves.

The stoke holds are arranged so that the air supply may be increased by means of fans, though the up-cast from the stoke hold remain open, and for this, four 6-foot double inlet fans were supplied, driven by engines $6\frac{1}{2}$ by 5 inches, and capable of running up to 600 revolutions per minute.

There are two up-takes and two funnels—one common to two boilers—the inside diameter of each funnel being 5 feet, and the height above the grate bars 45 feet.

The new boilers were made under a rigorous survey by the Admiralty surveyors; and, in accordance with the terms of the contract, one of the four boilers was erected at the constructors' works, and there subjected to tests by the Admiralty authorities, to determine its capacity and efficiency.

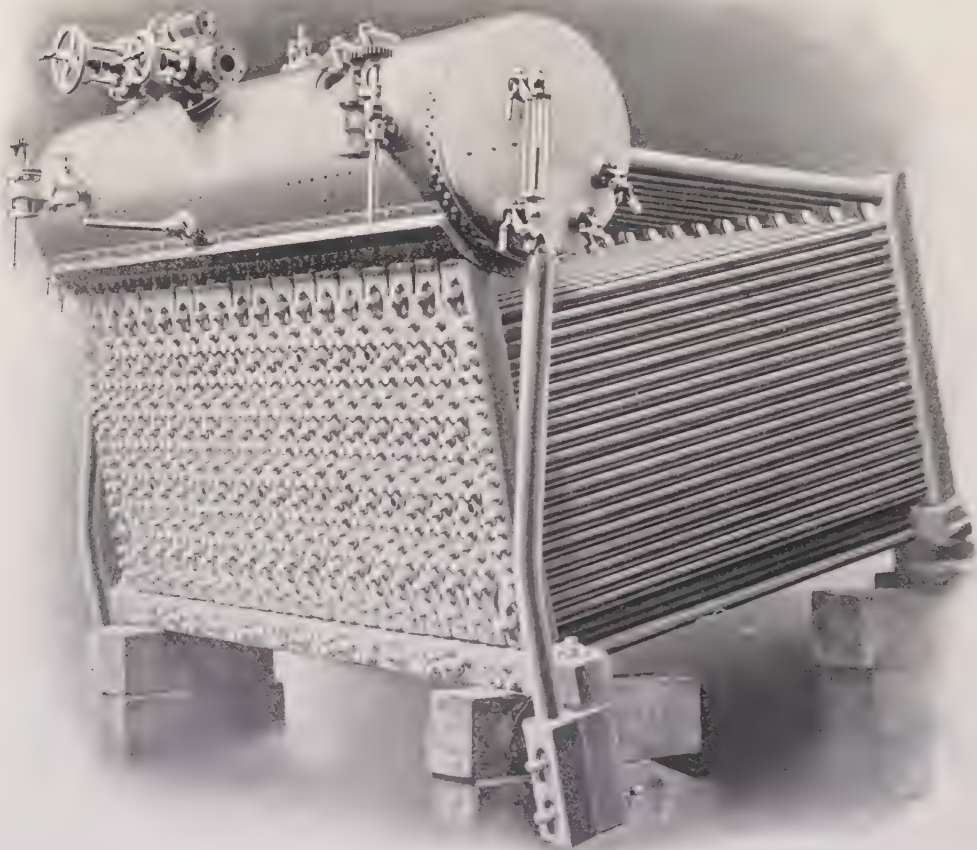
The guarantee to the Admiralty was that one of these boilers, steamed on shore, with natural draft, would evaporate 11,000 to 12,000 pounds of water per hour, with Welsh coal, and with the feed water at hot well temperature, 110 degrees Fahrenheit. With forced draft—not exceeding 3 inches of water, it was guaranteed to evaporate 18,000 to 19,000 pounds of water per hour from 110 degrees Fahrenheit for two hours continuously.

On the test boiler the ordinary draft was that due to a funnel fixed on the top of the boiler, 3 feet 6 inches diameter, and 45 feet high above the fire bars, corresponding to what the natural draft would be in one of these boilers in ordinary conditions of working on board ship. The assisted draft was

obtained by a steam jet placed in the funnel, the steam being taken from a $\frac{3}{4}$ -inch pipe, with the outlet reduced to about $\frac{1}{2}$ an inch in diameter.

No baffles were used to deflect the flame, or to reduce the area between the tubes.

In the table of tests, those having the Admiralty number were carried out by the Admiralty authorities, the others were made by permission of the Admiralty for the builders' observations.



H. M. S. "SHELDRAKE" BOILER, PRESSURE PARTS, CASING REMOVED

Permission was obtained from the Admiralty to place a feed heater in the up-take of the tested boiler for experimental purposes, but no heater is placed in the up-takes on board the "Sheldrake." It will be seen from the table of tests that this heater was removed after the fifth test.

In the first five trials it will be observed that the efficiency of 74.3 per cent. (E), with an evaporation at the rate of 4.87 pounds per square foot of heating surface, only falls to 72 per cent. (A), with an evaporation of 8.3 pounds per square foot of heating surface, and noting the intermediate trials (B, C and D), it shows that the efficiency, when evaporating up to 7 pounds of water per square foot of heating surface, is practically constant, and only above 7 pounds does the efficiency begin to fall. This proves the great elasticity in the working of the Babcock & Wilcox boiler—a result that could not possibly be obtained with the ordinary shell boiler—in other words, the amount of steam formed can vary between considerable limits without any fall in efficiency.

Tests G and D—the one with an evaporation of 5.18 and the other 5.13 pounds per square foot of heating surface—give efficiencies of 81 per cent. and 74.8 per cent., the higher efficiency of the former being due to the smaller air space between the bars.

With this boiler the highest efficiency with natural draft was obtained burning about 22 pounds of coal per square foot of grate surface, and $\frac{1}{8}$ of an inch air space between the bars.

BASIN TRIALS

The basin trials of this vessel took place at Devonport on the 14th, 15th, 16th and 17th of November.

The vessel was moored to the wharf in the usual manner in such trials, and the engines were allowed to run at such power as would take away all the steam formed by two of the boilers at a fixed rate of working. Two boilers only—alternatively those in the forward and aft compartments—were taken for each trial, so as to admit of more accurate observations.

The feed water was taken from the shore, and was carefully measured on its way to the boilers; the water from the hot well was allowed to run into the bilges.

On the 14th of November the two forward boilers were tried, burning 15 pounds of coal per square foot of grate, and on the 15th the two after boilers were tried at the same rate of combustion. These two trials were to determine the economic efficiency under a moderate rate of working.

On the 16th of November the two forward boilers were tried, burning 25 pounds of coal per square foot of grate, and on the 17th, the two after boilers were tried at the same rate of combustion; these latter trials were for the purpose of determining the economy at the maximum rate of working.

Each trial was of eight hours' duration, and was carried out with that scrupulous accuracy which is characteristic of Admiralty trials.

SEA-GOING FULL POWER TRIALS

The first sea trial, which took place on the 28th of November, was of eight hours' duration, and with all four boilers in use. This was an economy trial, 15 pounds of coal being burnt per square foot of grate per hour.

TABLE OF TESTS OF "SHELDRAKE" BOILER

Trials	A	B	C	D	E	G	H	I
Admiralty number	I.	II.	—	—	III.	IV.	V.	VI.
Date, 1897	May 14	19	22	24	25	28	June 8	8
Heating surface of boiler, square feet	2356	2356	2356	2356	2356	2356	2356	2356
Heating surface of heater, square feet	—	175	175	175	175	—	—	—
Grate surface, square feet	63	63	63	63	63	54	54	54
Fire bars used—A for Admiralty pattern, C for corrugated pattern	A	A	A	A	C	C	A	A
Air space between fire bars, inches	$\frac{1}{2}$ full	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{2}$ scant	$\frac{1}{2}$ scant
Kind of fuel used	Nixon's Nav'n Powell Duffryn's remaining 6 tests							
Duration of trial, hours	3	2	2	3	3	5	2	3
Kind of draft.—N for natural; I for induced	I	N	N	N	N	N	N	N
Amount of blast in inches of water in ash pit	0.25	0.2	—	0.1	0.1	0.2	0.1	0.3-0.4
Average observed gauge pressure—lbs. per square inch	185	190	200	200	200	200	200	200
Average observed temperature of water fed to heater, Fahrenheit	—	70	70	70	70	—	—	—
Average observed temperature of water fed to boiler, Fahrenheit	70	117.5	114	111	115	70	70	70
Pounds of coal fired, per hour	2564	2000	1650	1320	1260	1216	1290	2280
Pounds of refuse, per hour	487	260	91	67	75	64	194	251
Pounds of combustible, per hour	2077	1740	1559	1253	1185	1152	1096	2029
Pounds of coal consumed, per square foot of grate, per hour	40.7	31.74	26.19	20.9	20	22.5	24	42.2
Pounds of water evaporated per hour under actual conditions. Feed at 70° F.	19577	16650	15000	12200	11483	12210	11100	18216
Equivalent weight of water evaporated per hour with feed at 110°	20250	17222	15516	12619	11878	12630	11481	18842
Pounds of water evaporated per square foot of heating surface	8.3	7.06	6.36	5.13	4.87	5.18	4.7	7.7
Pounds of water evaporated per square foot of grate surface	310	264	238	193.5	182	226	205.5	337
Pounds of water evaporated per sq. ft. of heating surface from and at 212° per hr.	9.96	8.48	7.65	6.17	5.85	6.23	5.65	9.26
Pounds of water evaporated per sq. ft. of grate surface from and at 212° per hr.	372	316	286	232	219	271	248	404
Pounds of water evaporated per pound of coal per hour (water 70°, steam pressure 200 pounds, actual observed conditions)	7.63	8.32	9.09	9.24	9.11	10.04	8.6	7.99
Pounds of water evaporated per pound of coal per hour; from and at 212°	9.15	9.96	10.91	11.09	10.94	12.05	10.32	9.59
Pounds of water evaporated per pound of combustible per hour (water 70°, steam pressure 200 pounds, actual conditions)	9.4	9.56	9.6	9.77	9.69	10.6	10.1	8.97
Pounds of water evaporated per pound of combustible per hour; from and at 212°	11.28	11.47	11.52	11.72	11.6	12.72	12.12	10.7
Mean temperature of gases in funnel, F.	650°	—	—	—	—	550°	600°	200°
Mean temperature of gases above the heater, Fahrenheit	—	600°	650°	550°	550°	—	—	—
Mean temperature in up-take below the heater, Fahrenheit	—	650°	650°	650°	650°	—	—	—
Efficiency "A"	61.5%	67%	73.2%	74.5%	73.4%	80.9%	69.3%	64.4%
Efficiency "B"	72%	73.2%	73.5%	74.8%	74.3%	81.2%	77.4%	68.5%

N. B.—Efficiency "A" is the percentage of the total heat of coal that was actually transferred to the water, that is, *without* allowing for loss by unconsumed coal dropping through the bars, or ash.

Efficiency "B" is the actual efficiency, allowing 5% for ash, and making allowance for the coal that fell through the bars unconsumed, that is to say, these figures are established to show the result that would have been obtained on the assumption that the grate bars had been so arranged that no loss of unconsumed fuel took place, but only the loss by the usual percentage of ash or residue in the fuel.

The total heat of combustion of the coal has been taken at 14,400 British Thermal Units per pound

The temperatures of the gases were taken by noting the melting of pieces of metal, of a known melting point, placed in the funnel and up-take, and not by a pyrometer.

RESULTS OF SEA TRIALS

Date of Trial	November 28th, 1898	December 1st, 1898
Total grate surface in four boilers	252 square feet	252 square feet
Total heating surface in four boilers	9424 square feet	9424 square feet
AVERAGE PRESSURES:		
In boilers (gauge pressure)	152.5 pounds	151 pounds
In high-pressure casing (above atmosphere)	122 pounds	137 pounds
In intermediate-pressure casing (above atmosphere)	34 pounds	39 pounds
In low-pressure casing (above atmosphere)	15 absolute	6 pounds
Vacuum	25.8 inches	26 inches
Pressure of air supply to furnace, inches of water	0.2 inch	0.5 inch
Draft at base of chimney, inches of water	0.2 inch	0.3 inch
AVERAGE TEMPERATURES:		
External air	53° Fahrenheit	57° Fahrenheit
Boiler room	57° Fahrenheit	70° Fahrenheit
Escaping gases at root of funnel	550° Fahrenheit	550° Fahrenheit
Feed water	103° Fahrenheit	110° Fahrenheit
Discharge	76° Fahrenheit	82° Fahrenheit
Steam in boilers	366° Fahrenheit	365° Fahrenheit
FUEL:		
Coal consumed per hour	3776 pounds	6462 pounds
Total dry refuse	5 per cent.	6 per cent.
Quality of coal	Powell Duffryn	Powell Duffryn
POWER, SPEED, ETC.:		
Average indicated horse-power	2642	4050
Average revolutions per minute	242	280
Average speed of vessel per hour	17.9 knots	20.6 knots
Coal consumed per indicated horse-power per hour	1.429 pounds	1.57 pounds
Heating surface in square feet per indicated horse-power	3.5	2.3
Indicated horse-power per square foot of grate	10.5	16.

On December 1st a full power sea trial was made on the four boilers.

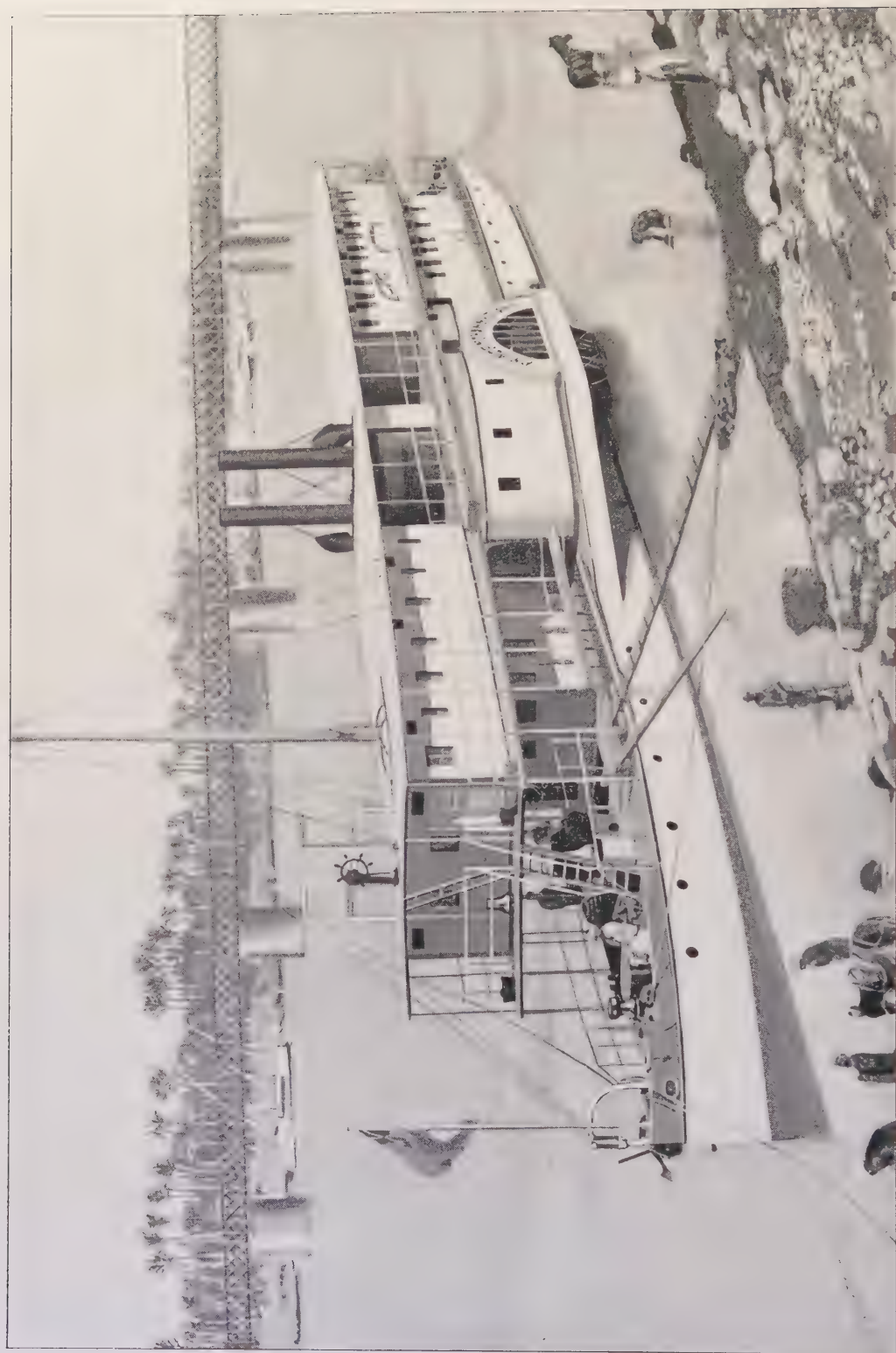
During these trials the temperature of the gases at the base of the funnel was taken every half hour, by noting the melting of chemically pure metals in a similar manner as for the trials on shore.

At the expiration of the full power trials, the Admiralty decided to further test the new boilers in actual sea service. Accordingly, an exhaustive series of nine tests was arranged, each test to cover a distance of 1000 miles.

During each of these trials the engines were run at a constant rate, and an accurate record kept of the coal burned. The three after boilers only were used, the fourth being held in reserve (cold).

The programme was as follows:

- Four 1000-mile runs with engines developing 1500 indicated horse-power at the rate of 500 indicated horse-power per boiler.
- Two 1000-mile runs with engines developing 1800 indicated horse-power at the rate of 600 indicated horse-power per boiler.
- Two 1000-mile runs with engines developing 2000 indicated horse-power at the rate of 666 indicated horse-power per boiler.
- One 1000-mile run with engines developing 2250 indicated horse-power at the rate of 750 indicated horse-power per boiler.



NILE PASSENGER STEAMER "MAHOMET ALI"

OWNERS: THOS. COOK & SON, LTD., CAIRO. BABCOCK & WILCOX BOILER, 225 INDICATED HORSE-POWER

The results obtained on these and the preceding basin and commissioning trials are as follows :

SUMMARY—BASIN AND SEA-GOING TRIALS

Date	Nature of Trial	No. of Boilers in Use	No. of Boilers in Reserve	Duration in Hours	Steam Pressure	I. H.-P.	Air Pressure in Stoke hold	Coal per I.H.-P. all Purposes	Coal per Square Foot Grate	Water per Pound Coal	Ashes per Pound Coal	Grate Surface
14-11-98	Evaporative	2	2	8	168	1116	.0	1.69	15.0	10.5	. .	126
15-11-98	Evaporative	2	2	8	179	1292	.0	1.46	15.0	10.5	. .	126
16-11-98	Evaporative	2	2	8	169	1761	. .	1.78	25.0	9.05	. .	126
17-11-98	Evaporative	2	2	8	165	1873	. .	1.67	25.0	9.34	. .	126
28-11-98	8 hours at 2500 I. H.-P. . .	4	. .	8	152	2642	.0	1.43	15.0	. . .	. .	252
1-12-98	3 hours at 3000 I. H.-P. . .	4	. .	3	151	4050	.43	1.57	25.6	. . .	. .	252
22- 2-99	3 hours commissioning . . .	4	. .	3	119	2735	.14	1.64	17.8	. . .	. .	252
28- 2-99	1000 miles at 1500 I. H.-P. .	3	1	69	120	1303	.0	1.61	12.8	. . .	.152	189
9- 3-99	1000 miles at 1500 I. H.-P. .	. .	1	68	120	1506	.0	1.6	12.67	. . .	.150	189
28- 3-99	1000 miles at 1500 I. H.-P. .	3	1	70	135	1534	.0	1.75	14.2	. . .	.200	189
20- 4-99	1000 miles at 1500 I. H.-P. .	3	1	68½	130	1539	.0	1.59	13.1	. . .	.150	189
5- 5-99	1000 miles at 1800 I. H.-P. .	3	1	67	135	1829	.0	1.6	15.4	. . .	.216	189
19- 5-99	1000 miles at 1800 I. H.-P. .	3	1	66½	140	1838	.0	1.68	16.4	. . .	.220	189
15- 6-99	1000 miles at 2000 I. H.-P. .	3	1	59	145	2033	.0	1.57	17.0	. . .	.220	189
3- 7-99	1000 miles at 2000 I. H.-P. .	3	1	61½	140	2042	.0	1.56	16.8	. . .	.230	189
20- 7-99	1000 miles at 2250 I. H.-P. .	3	1	56¾	150	2245	.0	1.63	19.4	. . .	.250	189
Total				632¾								
Mean					146	1974	. .	1.63		9.85	.198	. .

At the finish of the 1000-mile trials, several experiments were made. The first one was on the forward boiler, when the time required to raise steam to 140 pounds pressure from cold water was taken; the temperature of the water at the start was 70 degrees, and steam was raised to 140 pounds pressure in 23 minutes. After that a stopping and starting test was made; the engines were going full speed and suddenly stopped. The front tube doors and up-take doors were immediately opened and the ash-pit doors closed; the steam gauge was then watched and the pressure did not rise more than 5 pounds, neither did the safety valves lift.

The next test was made to ascertain how soon the operation of drawing a tube could be commenced after the fires were pulled out of the furnace. No. 4 boiler was used for this purpose. This boiler was worked at full power; suddenly the fires were drawn and the water blown out; in 24 minutes after hauling the fires several caps were taken off ready for drawing tubes. Then a test was made to show how quickly a tube could be taken out of a boiler. Three tubes were drawn one after the other; the first took 11 minutes, the second 10 minutes, and the third 9 minutes.

At the conclusion of these experiments, the "Sheldrake" had completed the whole of the Admiralty programme and returned to Devonport, where a careful examination was made of the boilers, which were found to be in as good a condition everywhere as when they left the works.



DREDGER FOR RUSSIAN GOVERNMENT FOR THE RIVER VOLGA

SYSTEM LINDON W. BATES (SOC. AN. J. COCKERILL, SERAING, BUILDERS)

THESE ARE THE LARGEST AND MOST POWERFUL DREDGERS IN EXISTENCE. STEAM IS SUPPLIED ENTIRELY BY BABCOCK & WILCOX BOILERS OF ABOUT 5600 HORSE-POWER

DREDGERS FITTED WITH WATER-TUBE BOILERS

RUSSIAN GOVERNMENT DREDGERS FIRED WITH NAPHTHA



NOVEL feature in the dredgers shown in the accompanying photograph, which have been built by Messrs. La Société Anonyme John Cockerill of Seraing, for the Russian Government, is the installation of water-tube boilers. These are of the Babcock & Wilcox marine type, and have given on the trials very great satisfaction.

There are four of these boilers on each hull half, making eight in all, having a total heating surface of 17,200 square feet. In addition to this a small boiler of the same construction is fitted in a stern wheel steamer, which is to act as a workshop and general tender to the dredger; this boiler has 1000 square feet of heating surface.

On the Russian official trials, which took place on the 24th to 29th of May, 1900, the boilers worked throughout without a hitch, giving an abundance of perfectly dry steam. On the full power trial, with all the machinery running, no trouble was experienced in keeping the water level constant, or in getting a sufficiency of steam, although working at a very high rate of evaporation, which would be, judging from the indicated horse-power of the engine, nearly 8 pounds of water per square foot of heating surface per hour.

On the stern wheel steamer, with the boiler of 1000 square feet heating surface, the boiler was forced to about double its rated capacity.

The boilers are fired exclusively with naphtha; there are four burners fitted to each boiler in the dredger, and two to the boiler in the stern wheeler.

The burners are made so as to swivel out from the furnace when requiring to be cleaned or examined. The spraying of the petroleum into the furnace is accomplished by a jet of steam. The oil by this means is vaporized and made ready for combustion. The temperatures taken of the funnel gases showed these to be very low, *i.e.*, not more than about 500 degrees F.

Any soot which may be formed at any time on the tubes can very readily be removed by means of suitable doors, which are provided in the boiler casing for the purpose; through these doors the whole of the heating surface of the boiler can be scraped or brushed, and as the whole of the interior of the tubes can be cleaned from scale, etc., it will be seen that if ordinary care in cleaning is taken, the boiler can always be relied upon to produce steam as efficiently after it has worked a long time as when first installed.

The boilers are constructed in such a manner that repairs can be readily carried out by the engineer's staff on board.



STEAM DREDGE "ARCHER"

OWNERS: QUEENSLAND GOVERNMENT, AUSTRALIA. SIX BABCOCK & WILCOX BOILERS, 2000 INDICATED HORSE-POWER

One of the advantages derived from the use of these boilers is the small amount of weight, as compared with ordinary boilers. The weight of the four boilers on one hull half, complete in working order with funnel, up-takes, and all accessories, was .02 tons per indicated horse-power developed on the trial.

DREDGERS "HERCULES," "SAMSON" AND "ARCHER"

The above vessels are sand-pump dredgers, and were built in 1900 by Messrs. Sir W. G. Armstrong, Whitworth & Co., Ltd., Newcastle-on-Tyne, all three ships being fitted with Babcock & Wilcox boilers, the first two ships with four boilers each, and the last with six boilers, a total aggregate heating surface of 44,300 square feet and grate surface of 1125 square feet.

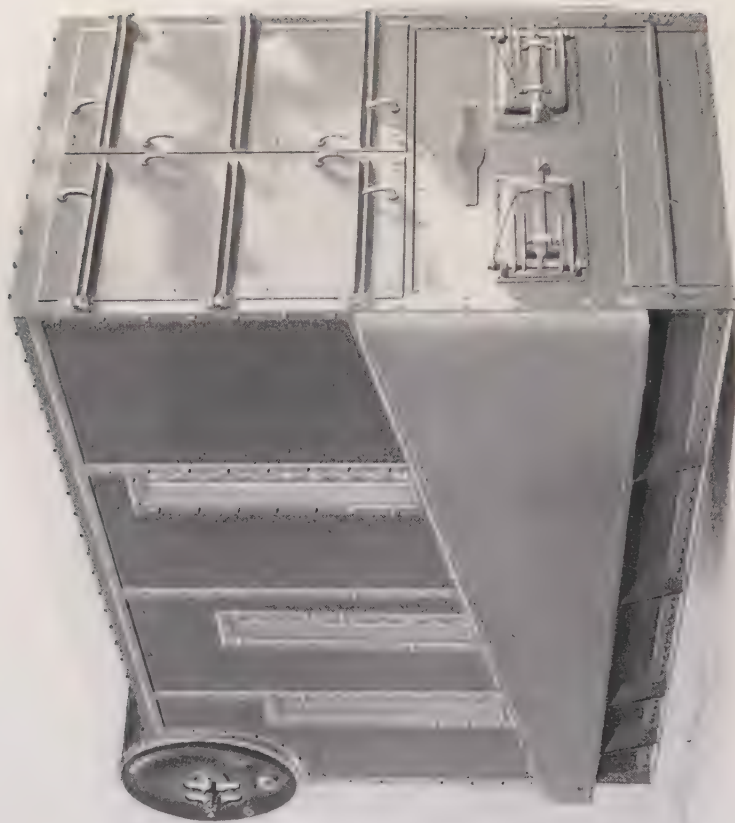
All three had satisfactory trials on the River Tyne and at sea, afterward proceeding to Australia under their own steam, where they will operate in the service of the Queensland Government. Information received from various ports of call indicated that the boilers were working most satisfactorily.

The boilers were made especially large to utilize inferior coals.

HOPPER DREDGE "ANTELEON"

The trial of this hopper dredge took place at Skelmorlie on August 3d, 1898. The vessel was built by Messrs. Simons & Co., of Renfrew, for the New South Wales Government, and is fitted with twin-screw propelling engines, each having cylinders 10, 15½ and 26 inches diameter by 16 inches stroke, indicating about 650 horse-power at 235 revolutions per minute. Two Babcock & Wilcox water-tube boilers supply steam to the propelling engines, pumping engines, and auxiliary machinery, and the total weight of the main engines and boilers is only 53 tons. Two runs were made in opposite directions at Skelmorlie (the vessel being loaded to full capacity), when a mean speed of over 9½ knots was obtained, the contract speed being only 8 knots. Further sand pumping trials were carried on at Brodick Bay, and on the result of these and the speed trials, Messrs. Simons are to be congratulated. This vessel may be quoted as another instance of the suitability of the Babcock & Wilcox boilers for all classes of vessels, and, as showing the reliance which may be placed upon the boilers, it is intended that this vessel will steam out to Sydney, N. S. W. It may be mentioned that the "Anteleon" is the fourth Scotch-built vessel into which the Babcock & Wilcox boilers have been fitted within the past year or so.—*The Steamship*.

It is interesting to note that the "Anteleon" steamed to Sydney, N. S. W., in eighty days, and on arrival the boilers were found to be in excellent condition.



SEMI-MARINE BABCOCK & WILCOX BOILER—PATENTED

INSTALLED IN DREDGE "TEXAS CITY" AND FLOATING DRY DOCK "ALGIERS"

DREDGE "TEXAS CITY" AND FLOATING DRY DOCK "ALGIERS"

The steam dredge "Texas City," built in the spring of 1900, was equipped with a Babcock & Wilcox boiler of the semi-marine type. This style of construction is somewhat heavier than the marine and not quite so compact, favoring the land or stationary boiler in appearance; the tubes forming the heating surface being 4 inches in diameter and from 12 to 14 feet in length. Around the boiler is fitted an air-tight wrought-steel casing, which contains asbestos, magnesia and light fire tile placed against the side tubes. The boiler is supported upon a plate and channel girder, thereby distributing the weight of the structure over a large area.

Four boilers of this class have been installed on the United States Government floating dry dock "Algiers."



STEAM DREDGE "TEXAS CITY"
CAPACITY, 3500 CUBIC YARDS OF BLUE AND RED CLAY PER DAY



PONTOON PIPE LINE
FROM DREDGE TO DUMPING GROUND



DISCHARGE OF 20-INCH PIPE
1000 FEET FROM DREDGE

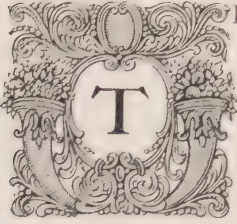


HOPPER DREDGE "ANTELEON"

BALDWIN & WILSON BOILERS (See page 65), 700 INDICATED HORSE-POWER

OWNERS: NEW SOUTH WALES GOVERNMENT

FUEL—ITS COMBUSTION AND ITS HEAT VALUE



THE term "fuel," in its widest sense, may mean any substance which, by its combination with oxygen, evolves heat. It is generally applied, however, to those substances which are in common every-day use for heat-producing purposes.

Coal is the fuel most extensively used, and while sawdust, rice-chaff, bagasse, wood, etc., are not uncommon fuels for making steam on land, coal is practically the only kind that need be considered in marine practice.

The nature and quality of coal, in point of view of its heating value, vary considerably. It is a fossil of vegetable origin, and the difference in its nature is attributed to the variation in its origin. Coal from the same stratum does not vary in its nature or characteristics, and generally these characteristics are the same in a certain district, hence the district from which a certain coal is obtained usually determines its commercial designation.

Coal is divided into two main classes—anthracite and bituminous.

"Anthracite" is a word of Greek origin, meaning "carbon" or "coke," the fuel being so named probably because it is that which contains the largest percentage of fixed carbon.

"Bituminous" is of Latin origin, meaning "containing or resembling bitumen."

There are various degrees in the nature of these coals, which may be enumerated as follows: Anthracite, or hard coal; semi-anthracite; semi-bituminous; bituminous, or soft coal; and lignite.

Pure anthracite coal—which is said to be the oldest and deepest formation—is found principally in the United States of America. It is also found in the western part of the South Wales coal fields; in the neighborhood of Swansea; in some parts of Scotland; to a small extent in France; in the South of Russia; and in the Osnabrück district of Westphalia, Germany.

Semi-anthracite coal closely resembles anthracite in its physical characteristics and appearance, but contains less fixed carbon and burns more freely. It is represented by what is known as "Welsh anthracite," and by coals from a limited territory in Pennsylvania.

Semi-bituminous coal is most largely represented by the "Cardiff" or "Welsh" coals from the enormous fields of South Wales, and in the United States by the rich deposits on the slope of the Appalachian Mountains, extending from Clearfield County, Pa., to the southern boundary of Virginia, the coals in this belt taking the names of "Pocahontas," "George's Creek," "Clearfield," etc. The Belgium coal, known as "Demigras," is also of this class.

Bituminous coal is found almost all over the world. The largest known fields, generally speaking, are in Scotland, England and the United States.



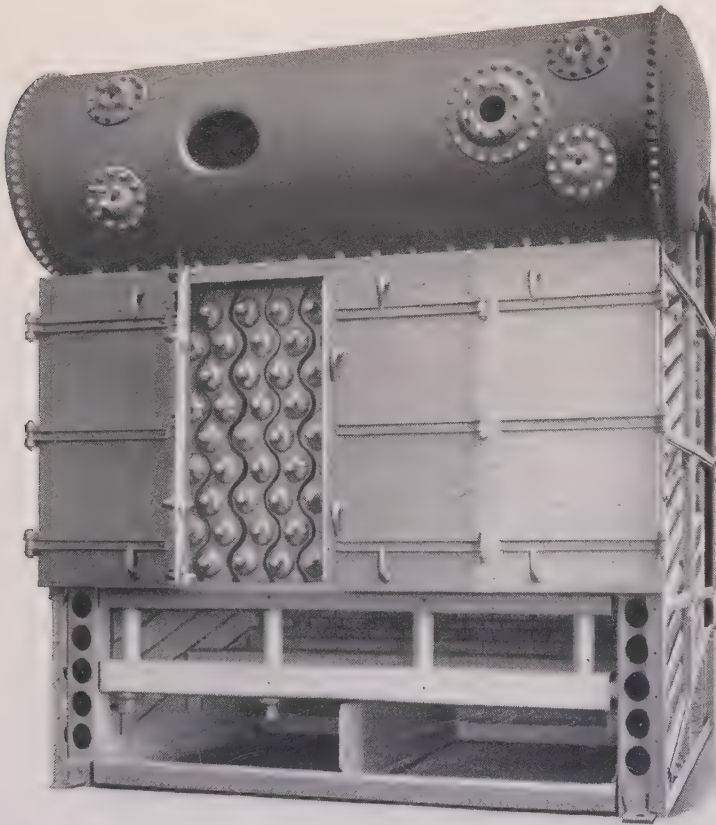
U. S. S. "ATLANTA"
FITTED WITH FOUR BABCOCK & WILCOX MARINE BOILERS

It is found in less quantity, in Germany in the Ruhr district, in Westphalia and Silesia, in the north of France, Austria, Russia, China, Japan, India, Australia, New Zealand and Canada.

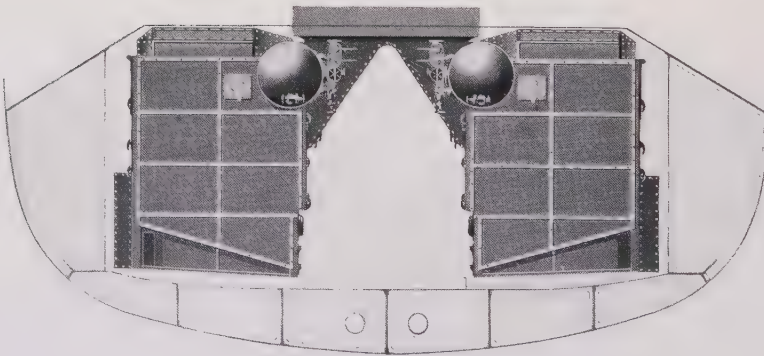
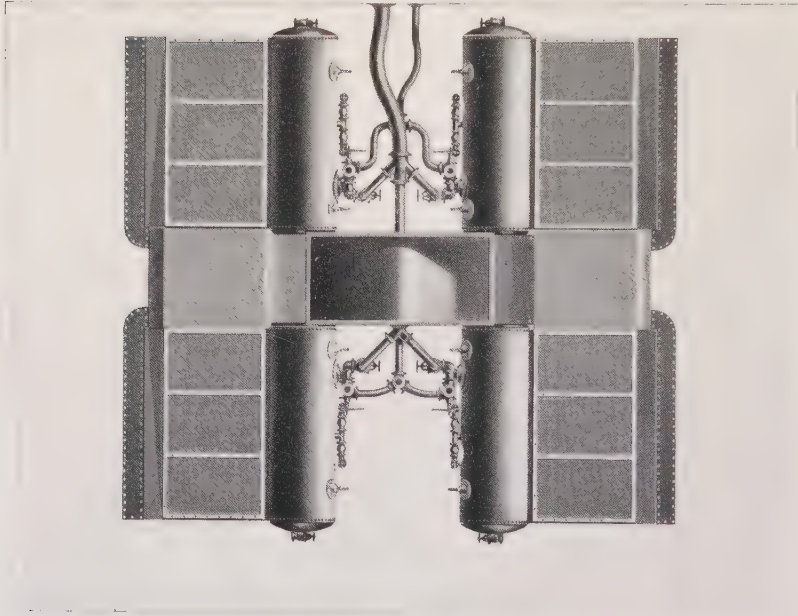
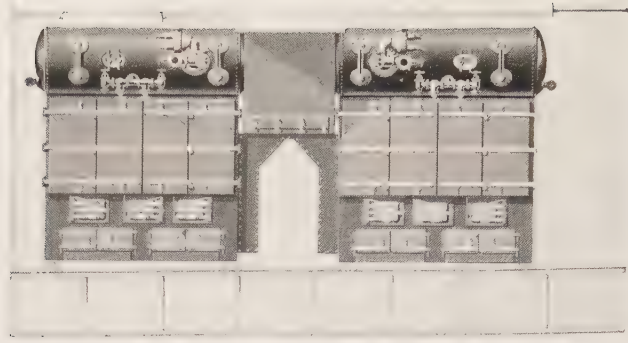
"Cannel" coal, a variety of bituminous coal, is found in the Midlands of England and in the United States. It is used principally for making illuminating gas and for domestic purposes.

The principal lignite fields are in France, Italy, Germany and Austria, but lignite is also found in the United States and in Sweden.

The theoretical heating value of fuel is the heat which it develops when consumed under theoretically correct conditions—which are practically only obtained in the laboratory—and it is expressed in heat units or thermal units. In England and the United States of America the British thermal unit is adopted, this being the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.



STEAM DRUM AND TUBE DOORS OF BABCOCK & WILCOX MARINE
BOILER, U. S. S. "ATLANTA"



ARRANGEMENT OF BABCOCK & WILCOX BOILERS IN U. S. S. "ATLANTA"
 TOTAL HEATING SURFACE, 7600 SQUARE FEET. GRATE, 212 SQUARE FEET

On the Continent of Europe the "calorie" is used, and the standard is the heat required to raise the temperature of one kilogram of water one degree centigrade.

To convert calories per kilogram of coal into British thermal units per pound of coal, multiply by 1.8.

The theoretical heating value of the above-mentioned coals varies between 7000 and 15,500 British thermal units per pound, depending largely on the varying amounts of incombustible matter or ash that the coals contain.

The semi-bituminous coals of the Pocahontas and Cardiff varieties are the most uniform in this respect, the ash being only 3 to 8 per cent.; Belgian "Demigras" will run from 5 to 15 per cent., while the residue in Transvaal coal may reach 25 to 35 per cent.

The anthracite coals, as mined, contain from 15 to 30 per cent. of refuse or slate. Most of this, however, is usually removed when the coal is prepared for the market, so that anthracite, as sold, may contain as little as 3 per cent. On the other hand, the smaller sizes may run very high in ash, and cases have been known where 50 per cent. refuse has been found in boiler tests.

Bituminous coals are extremely variable, running from 5 to 35 per cent. ash, while the percentage in lignite is usually considerably under 10.

The heat value of the combustible portion of the coal (ash and moisture deducted) is also quite variable, and depends on the quality of the volatile matter, which may be either very rich in hydrocarbons, as in semi-bituminous coals, or comparatively high in oxygen, as in many of the bituminous coals and lignite. So much, in fact, does the amount of oxygen found in lignite detract from the calorific value of the volatile matter, that the combustible portion of lignite is worth only about three-fourths that of semi-bituminous coal.

APPROXIMATE CHEMICAL COMPOSITION OF SEVERAL TYPICAL KINDS OF SOLID FUELS

	Moisture	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Wood, perfectly dry	0	50	6.0	41.5	1.0	...	1.5
Wood, ordinary	20.0	40	4.8	33.2	0.8	...	1.2
Peat	30.0	40.6	4.2	21.7	...	...	3.5
Charcoal	12.0	84	1.0	0	...	...	3.0
Straw	16.0	36	5.0	38.0	...	...	5.0
Coal, anthracite	1.0	86	1.0	1.0	0.5	0.5	10.0
Coal, semi-bituminous	1.0	84	4.2	3.4	0.8	0.6	6.0
Coal, bituminous, Pittsburg	1.4	75	5.0	8.0	1.0	1.6	8.0
Coal, bituminous, Hocking Valley, O.	7.5	67	4.8	10.0	1.2	1.5	8.0
Coal, bituminous, Illinois	11.0	56	5.0	11.0	1.0	3.0	13.0
Brown coal, Pacific coast	16.8	50	3.8	13.6	0.9	...	13.2
Lignite, Pacific coast	14.0	55	4.0	15.0	1.0	1.0	5.0

The above table shows approximately the composition of several typical kinds of fuel.



U. S. MONITOR "WYOMING"

FOUR BARCOCK & WILCOX BOILERS, 2400 INDICATED HORSE-POWER

The elements in the coal from which we derive heat are carbon in its solid state, hydrogen, and sometimes a little sulphur. The hygroscopic water which it contains is injurious, as it absorbs heat for its own evaporation.

The heat value of the fuel may be calculated from the analysis by means of Dulong's formula, as follows: B.T.U. per pound equal

$$146 C + 620 (H - \frac{1}{8}O) + 40 S$$

in which C, H, O and S are, respectively, the percentages of carbon, hydrogen, oxygen and sulphur in the fuel, and the constants are the most recent average heat values for carbon, hydrogen and sulphur, each divided by 100.

The actual heating value of a coal, as determined by test with an instrument known as a "bomb calorimeter" (see page 88), agrees very closely with that calculated from the analysis, usually within 2 per cent., when both the analysis and the calorimeter test are made by a skilled chemist.

The analyses given in the foregoing table are called "ultimate analyses," since the constituents of the fuel, except the moisture and ash, are reduced to the ultimate chemical elements. Another kind of analysis, called "proximate analysis," is more commonly used, which separates the coal into four parts, viz.: moisture, volatile matter, fixed carbon and ash.

The proximate analysis is of great value for indicating the general character of a coal. By dividing the percentages of volatile matter and fixed carbon each by their sum, we obtain the percentages of each in the "combustible," or coal dry and free from ash. These percentages serve to identify the class to which the coal belongs, as follows:

Class of Coal	Fixed Carbon per cent. of Combustible	Volatile Matter per cent. of Combustible
Anthracite	100 to 92	0 to 8
Semi-anthracite	92 to 87	8 to 13
Semi-bituminous	87 to 75	13 to 25
Bituminous	75 to 50	25 to 50
Lignite	below 50	over 50

These various kinds of coal act very differently during their combustion in a furnace, and to get the best results each must be handled in the way best suited to its characteristics; and the size and design of the furnace must also be adapted to the particular requirements of the coal.

With anthracite coal disintegration and distillation take place very slowly, with semi-bituminous coal they take place somewhat faster, and with bituminous coal almost instantaneously, the rate depending on the percentage of fixed carbon.

For the combustion of one pound of carbon 2.66 pounds of oxygen are necessary, and as the air contains only 23 per cent. of oxygen, it follows that 11.6 pounds of air are necessary for the combustion of one pound of carbon.



S. S. "PRESQUE ISLE"

426 FEET LONG, 50 FEET BEAM, 28 FEET DEEP, DRAFT LOADED, 17 FEET. OWNERS: PRESQUE ISLE TRANSPORTATION COMPANY, CLEVELAND.
CARRYING CAPACITY, 6300 TONS. TWO BABCOCK & WILCOX MARINE BOILERS, 2000 INDICATED HORSE-POWER

The air required for combustion in a boiler furnace has to pass through the spaces between the grate bars, and the layers of fuel on them, the rapidity with which it passes through depending on the intensity of the draft and condition of the fire.

When the fuel is supplied in too great a quantity, or the supply of air is insufficient, the carbonic acid, formed in the lower layers of the fuel, takes up another portion of carbon in the upper layers, and forms carbonic oxide or carbon monoxide, which passes through the boiler unconsumed, and frequently re-ignites at the top of the funnel, where it comes into contact with sufficient air to enable its combustion to be completed. Thus, flaming at the top of the funnel, or in the flues beyond the boiler, is generally a sure sign of unsatisfactory conditions of combustion.

Anthracite coal, and coke, may be called comparatively slow combustion fuels, and to provide that a certain quantity shall be consumed for a given size of boiler, either the grate surface must be increased, as compared with bituminous coal, or the intensity of the draft—in other words, the velocity of the air supply—must be increased. From this arises the fact that when burning anthracite coal in a boiler furnace proportioned for bituminous coal, either an extra high funnel is required, or an artificial method of intensifying the draft, commonly called “forced draft,” must be used.

Anthracite and semi-anthracite are the coals for which it is easiest to design a suitable furnace, and experience has shown that with all types of boilers, for these fuels the plain level grate is the most practical; it is the cheapest in up-keep, and it requires the least skill on the part of the fireman.

Naturally, the size of lump, the percentage of ash, the rate of combustion required, and the strength of draft, determine such details as width of bar, extent of grate surface, form of bar, and size of air opening.

With semi-bituminous coal, owing to its larger percentage of volatile matter and the rapidity with which this inflammable gas is distilled off, more space must be provided in the furnace and care taken to prevent the burning gases coming in contact with the boiler heating surface and being cooled before combustion is complete.

These points are still further accentuated in relation to bituminous coal and lignite, and neglect to observe their importance leads to great loss in the use of these fuels.

The best methods of handling semi-bituminous coal and the bituminous coal having the larger percentage of fixed carbon, is to fire it on the front end of the grate, where it is “coked,” the volatile gases passing back over the incandescent fuel and burning completely before touching the heating surface. The coke left on the front is then pushed back and a fresh charge of coal fired.

With the very volatile bituminous coals and lignite, it is impossible to handle the fuel in this way, as it does not coke and has a tendency to form bad



STEAM TUG "HOTSPUR"

OWNERS: THE LONDON AND INDIA DOCKS JOINT COMMITTEE. TWO BABCOCK & WILCOX BOILERS, 880 INDICATED HORSE-POWER. BUILT BY
 WILLIAM SIMONS & Co., RENFREW. REPEAT ORDER GIVEN IN 1898 TO MESSRS. R. & H. GREEN, LTD., BLACKWALL.
 LONDON FOR SIMILAR VESSELS: FRANKLIN, GREEN, SIMONS & CO., LONDON.

and troublesome clinker when worked with the fire tools. This fuel should be spread in very light charges evenly from the front to the back, covering each half of the grate alternately.

Semi-bituminous and the coking variety of bituminous coal may also be fired in this way with no loss in economy if the firing is skillful.

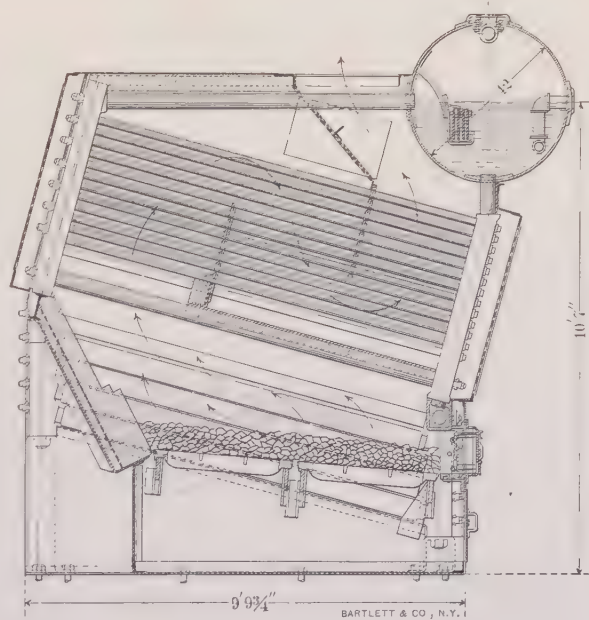
The method of firing and the design of the furnace have a material effect on the production of smoke; but it may be mentioned that while smoke is an indication that the conditions of combustion are susceptible of improvement, an absence of smoke is not by any means a sure sign of proper combustion, for it may be brought about by too much air being supplied, and consequent dilution of the gases; nor is the production of smoke by any means an indication that much waste takes place, for the quantity of unconsumed carbon sufficient to color the escaping gases from a boiler is an exceedingly small percentage of the total amount of fuel.

The Babcock & Wilcox Marine Boiler, here illustrated, is the best of all water-tube boilers, so far designed, for obtaining a high efficiency with bituminous coals.

It will be seen that the gases evolved from the fuel, pass under the roof located over the front portion of the lowest row of tubes, to a high combustion chamber at the rear, and are thoroughly mixed and burned before entering the bank of tubes forming the heating surface.

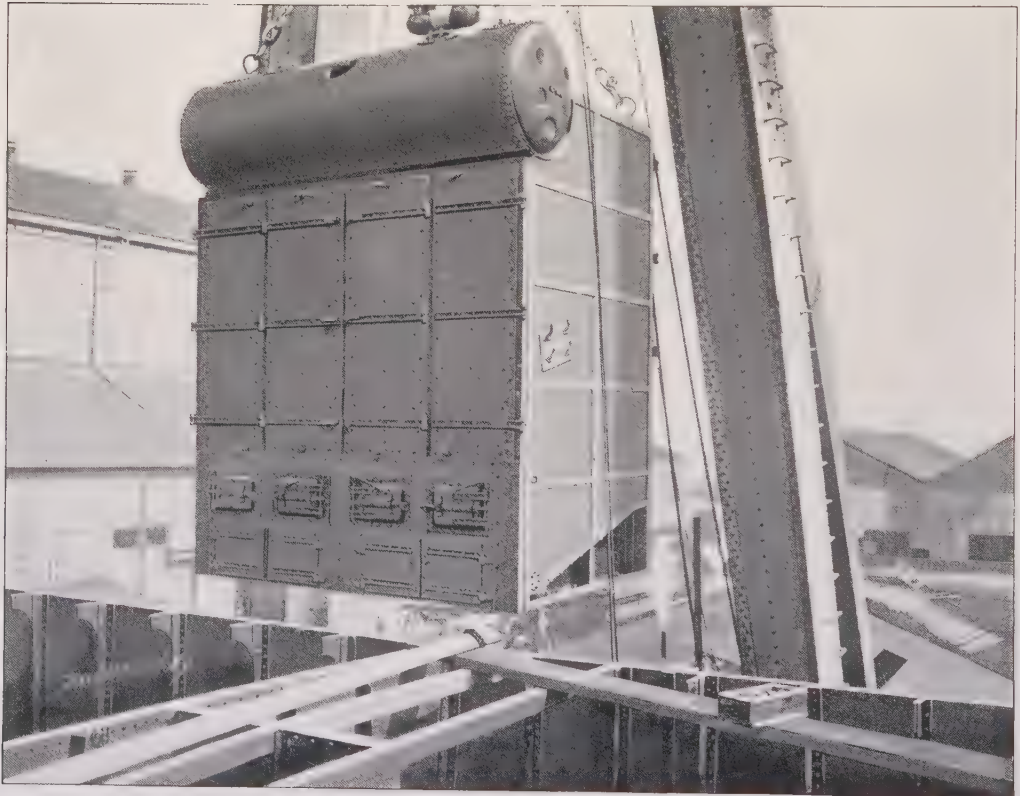
Generally speaking, with this boiler and with careful firing and favorable conditions, from 70 to 75 per cent. of the heat units which a

coal is found to contain theoretically, can be transferred to the water and steam. Claims have been made that more than this can be obtained—up to 80 per cent.—with certain classes of boilers; we do not wish to dispute the possibility of obtaining this, but certainly it is only obtainable under conditions which are so carefully studied as to be impracticable or impossible to maintain in ordinary practice. The remaining 30 per cent. is lost in radiation, in the heat carried away in the waste gases, and in imperfect combustion, due either to unavoidable excess of air in the furnace, or to a lack of sufficient air, depending upon the furnace conditions. A greater proportion of the heat



can usually be saved and utilized when anthracite and semi-bituminous coals are employed. And as the volatile matter in the fuel increases, the greater becomes the probable loss from incomplete combustion.

Higher evaporative efficiencies can generally be obtained from water-tube boilers than from shell boilers, for the reason, principally, that in the former there are furnaces which are capacious, and in which combustion takes place more quickly than in the furnaces of shell boilers, where not only is the space for combustion confined, but the fuel surrounded by cool boiler surface.



METHOD OF HANDLING A BABCOCK & WILCOX BOILER INTO A STEAMER

HEAT VALUES OF COAL

B.T.U. PER POUND OF DRY COAL—CALORIES PER KILO. DRY COAL

UNITED STATES

Name and Locality of Mine	B. T. U.	Calo-ries	Authority	Name and Locality of Mine	B. T. U.	Calo-ries	Authority
ALABAMA:				OHIO:			
Blue Creek, mine run	11931	6628	} W. B. Phillips	Brier Hill, lump	13600	7556	} Carpenter The B. & W. Co.
Henry Ellen, lump	13608	7560		Jackson, lump	13613	7563	
Mary Lee	13314	7397	} The B. & W. Co.	Cambridge	13075	7264	} Lord & Haas
Pratt, lump	12835	7134		Hocking Valley, lump	13102	7279	
Old Pratt, No. 4 lump	14580	8100		Hocking Valley, mine run	12571	6984	
ARKANSAS:				Palestine	13387	7437	} Lord & Haas
Coal Hill	13452	7473	} St. Louis Sampling Works	Salineville	13464	7480	
Eureka	12254	6808		Yellow Creek	13603	7557	
Lignite	9215	5119	B. & W., Ltd.	Waterford	13637	7576	
COLORADO:				PENNSYLVANIA:			
Diamond, Jerome Park	13103	7280	} Carpenter	Anthracite			
New Caste, mine run	12069	6795		Buck Mountain, buck-wheat	12308	6838	} The B. & W. Co.
ILLINOIS:				Cross Creek	11520	6400		} Barrus
Paisley, screenings	10942	6079	} The B. & W. Co.	Honey Brook	11732	6518	
Pana, screenings	10565	5869		Avondale	13219	7344	} Carpenter
Big Muddy, lump	13490	7444	Drifton, buckwheat	13722	7623		
Ladd, lump	12450	6917	Lackawanna	12371	6873		
Staunton, lump	11568	6393	Lykens Valley, buck-wheat	11902	6612		
Seatonville, lump	12000	6667	} Carpenter	Scranton Forty Foot	13050	7250	
Streator, lump	12600	7000			Bituminous		
Streator, screenings	12200	6778		Connelsville	13683	7602	} D. Ashworth
Wilmington, screenings	9759	5417		Duquesne, mine run	14285	7936		} Woodman
Wilmington, washed screenings	12109	6722		Catsburg	13858	7646	
INDIANA:				Beaver Creek	13450	7472	} Lord & Haas
Brazil, block	13629	7572	} Noyes, McTaggart and Craven	Carnegie	14047	7804	
New Pittsburg	12369	6872		Creedmore	13640	7578	
Brazil, semi-block	12560	6944	Carpenter	Hoytdale	13403	7446	
INDIAN TERRITORY:				Turtle Creek	13547	7526	} The B. & W. Co.
McAlester, slack	10512	5840	} St. Louis Sampling Works	Pittsburg, nut and slack	13280	7378	
McAlester, washed slack	10903	6057		Youghiogheny	12941	7190	
Krebs, lump	12874	7152		TENNESSEE:			
KENTUCKY:				Glen Mary	12542	6668	} Anonymous The B. & W. Co.
Vanderpool, lump	13460	7444	Carpenter	Crooked Fork	12542	6668	
MARYLAND:				VIRGINIA AND WEST VIRGINIA:			
George's Creek	14216	7808	} Barrus	VIRGINIA:			
Eureka	13652	7585		Elk Garden	13180	7322	} Barrus
Cumberland, mine run	13600	7580	} The B. & W. Co.	Pocahontas, Flat Top	14800	8222		} The B. & W. Co.
Cumberland, mine run	14343	7952		Pocahontas, mine run	14355	7975	} Lord & Haas
MISSOURI:				Thacker	14182	7879		} The B. & W. Co.
Hamilton	11662	6479	} Forsyth	Fairmont, mine run	13830	7683	
Frontenac, lump	9743	5413		St. Louis Sampling Works	New River, mine run	14488	8049
Glen Oak	9767	5426		Nuttallburg, mine run	14889	8232	
				Thermont, mine run	14352	7973	

ENGLAND, GERMANY, FRANCE, BELGIUM AND AUSTRIA-HUNGARY

Coals, Locality of Beds	B. T. U.	Calo-ries	Nature	Coals, Locality of Beds	B. T. U.	Calo-ries	Nature
GREAT BRITAIN				GREAT BRITAIN			
WELSH COALS				CONTINUED			
Ebbw Vale, 1848	16214	8998	} Almost pure anthracites, having 84 to 89% of carbon	Gwaun Cae Gurwen	15123	8402	} Pure, hard anthracite
Powell Duffryn, 1848	15715	8710		Newcastle	14820	8225	
Llangennech, 1848	14998	8318		Derbyshire and York-shire	13860	7692	} Bituminous coal, having 77 to 82% of carbon
Llangennech, 1871	14964	8305		Lancashire	13918	7724	
Graigole, 1848	14680	8152		Scotch	12870	7150	} Bitu. coal, having 78% of carbon
Nixon's Navigation	15000	8325					

EUROPEAN COUNTRIES—CONTINUED

Coals, Locality of Beds	B. T. U.	Calo-ries	Nature	Coals, Locality of Beds	B. T. U.	Calo-ries	Nature	
GERMANY				FRANCE				
RHENISH PRUSSIA:				CONTINUED				
Dortmund, Ruhr coal	14518	8066	Cannel coal	BASSIN DE LA LOIRE:				
Witten, Ruhr coal	15125	8403		Rive-de-Gier, Cime- tière 2	15309	8505	Bituminous, hard coal, long flame	
Bochum, Ruhr coal	13514	7508		Rive-de-Gier, Cou- son	14770	8206		
Bommern, Ruhr coal	13212	7340	Short flame coal, semi-anthracite					
Essen, Ruhr coal	14985	8325	Cannel coal	BASSIN DE L'AVEYRON:				
Saar-coal	11511	6395		Lavaysse	14630	8128	Bituminous, hard coal, long flame	
SAXONY:				Céral	13203	7335	Semi-bituminous coal	
Zwickau	11964	6647	Cannel coal	Bassin d'Alais Roch- belle	15643	8691	Bituminous, coking	
Hohndorf	11343	6302						
Oelsnitz	10674	5930						
LOWER SAXONY, AN- HALT AND BRUNSWIG:				BASSIN DE VALEN- CIENNES:				
Unseburg	5769	3205	Brown coal or lig- nite, low grade	Denain Fosse Renard	15244	8469	Bituminous coal, long flame	
Atzendorf	6444	3580		Denain Fosse Lelvet 1	15100	8389		
Neudorf	6093	3385		Denain Fosse Lelvet 2	15316	8509		
Görzig	3853	2140		St. West, Fosse de la Réussite	15105	8392	Bituminous coal, short flame	
Halle a. S.	4165	2314		St. West, Grande Fosse	15188	8438		
Bitterfeld	3830	2128		St. West, Fosse Tin- chon	15082	8379		
Naumburg	4563	2535	Bituminous	Anzin, Fosse Chauf- four	14353	7974	Bituminous, coking	
HANOVER:				Anzin, Fosse la Cave	14549	8083		
Osnabrück	10789	5994	Semi-anthracite, low grade	Anzin, Fosse St. Louis	15397	8554		
Obernkirchen	12718	7066	Bituminous	Fresne, Fosse Bonne- parte	15228	8460	Semi-bituminous coal	
SILESIA (PRUSSIA)				Vieux-Condé, Fosse Sartean	15409	8561		
Carlssegen	10422	5790	Long flaming, semi- bituminous	BELGIUM				
Myslowitz	10758	5977		BASSIN DE MONS:				
Waterloo	11412	6340		Haut-fleuu	14576	8098	Semi-bituminous, hard coal	
Königshütte	12247	6804		Belle et Bonne, fosse No. 21	14326	7959		
Paulusgrube	12425	6903		Levant du fleuu	14508	8060		
Waldenburg	12637	7021		Couchant du fleuu	14446	8037		
Brandenburg	12193	6774		Midi du fleuu	14553	8085		
Neurode	13393	7441		Grand-Hornu	14943	8302		
Freienstein	9651	5362		Nord du bois de Bossu	14407	8004		
Maxgrube	10087	5604		Grand-Buisson	14877	8265		
BAVARIA:				Escouffiaux	15217	8454		
Hanshamer coal	6821	5456	Lignite or brown coal, low grade	St. Hortense, bonne veine	15107	8393		
Peipenberg	8186	4548		BASSIN DU CENTRE:				
Penzberg	8921	4956		Haine St. Pierre	14702	8168		
FRANCE				Bois du Lac	14358	7977	Semi-bituminous, coking coal	
Anthracite de la May- enne	15566	8646	La Louvière	15127	8404			
Anthracite de La- mure (Isère)	13782	7657	Bracquignies	15363	8535			
BASSIN DU BAS-DE- CALAIS:				Mariemont	15168	8427	Bituminous, hard coal	
Marles	14175	7875	Bascoup	14911	8284			
Bully	15120	8400	Sars-Longchamps	14895	8275			
Hessin	15352	8529	Houssu	14945	8303			
Lens	15258	8477	BASSIN DE CHARLEROI					
Naux	15256	8476	Semi-bituminous coal	St. Martin, Fosse No. 3	14954	8308	Semi-bituminous, coking	
l'Escarpelle	15400	8556		Triekukaisin	15069	8372		
les Courrières	14265	7925		Poirier, Fosse St. Louie	14421	8012		
BASSIN DE LA SAÔNE				Bayemont, Fosse St. Charles	13806	7670		
Blanzay	13127	7293		Sacré-Madame	15204	8447		
Epinaç	14086	7826		Sars-les-Moulins, Fosse No. 7	15125	8403	Semi-bituminous, hard coal	
BASSIN DE LA LOIRE:				Carabinier-française, No. 2	14911	8284		
Rive-de-Gier puits Henry	15481	8601		Roton, veine Greffier	14311	7951		
Rive-de-Gier, No. 1	15472	8596		Pont-du-Loup	14947	8304		
Rive-de-Gier, Cime- tière 1	14493	8052						

EUROPEAN COUNTRIES—CONTINUED

Coals, Locality of Beds	B. T. U.	Calo- ries	Natur	Coals, Locality of Beds	B. T. U.	Calo- ries	Nature	
AUSTRIA-HUN- GARY				AUSTRIA-HUN- GARY				
LOWER AUSTRIA :				CONTINUED				
Grünbach	11458	6366	Semi-bituminous coal	SILESIA :				
Thallern	7057	3921	Lignite or brown coal	P. Ostran	12564	6980	Bituminous coal	
				Orlan-Lazy	12389	6883		
				Poremba	11057	6143		
				Karwin	13021	7234		
UPPER AUSTRIA :				Taklowetz	11932	6632		
Wolfsegg-Trannthal	6006	3337	Lignite or brown coal	HUNGARY :				
STYRIA :				Fünfkirchen	10276	5709	Cannel coal	
Leoben	9666	5370	Lignite or brown coal	Anina	11356	6309		
Fohnsdorf	9187	5104		Neufeld	5200	2889		
Göriach	6222	3457		Brennberg	8325	4625		
Köflach	6867	3815		Aika	6913	3841		
Wies	7997	4443		Salgor-Tarjan	7966	4426		
Trifail	7556	4198		Dorog-Annathal	7709	4283		
BOHEMIA :				Tokod	8069	4483		
Kladno	10675	5931	Semi-bituminous coal	DALMATIA :				
Buschtehrad	8865	4925		Siveric	8087	4493	Lignite or brown coal	
Libuschin	9900	5500		ISTRIA :				
Schlan	7979	4433			Arsa	10182	5657	Lignite or brown coal
Rakonitz-Lubna	7257	4032			TRANSYLVANIA			
Pilsen	9318	5177	Lignite or brown coal	Petrozsény	11286	6270	Lignite or brown coal	
Schatzlar	9552	5307		Egeres	8692	4829		
Aussig	6408	3560		BOSNIA :				
Dux	7805	4338		Zenica	7911	4359	Lignite or brown coal	
Bilin	8182	4546						
Brüx	8274	4597						
MORAVIA :								
Rossitz	12553	6974	Lignite or brown coal					
M. Ostran	12623	7013						
Gaya	4858	2699						
Göding	5056	2809						

TEMPERATURE OF FIRE

The following table, from M. Pouillet, will enable the temperature to be judged by the appearance of the fire :

Appearance	Temperature Fahrenheit	Appearance	Temperature Fahrenheit
Red, just visible	977°	Orange, deep	2010°
Red, dull	1290	Orange, clear	2190
Red, cherry, dull	1470	White heat	2370
Red, cherry, full	1650	White bright	2550
Red, cherry, clear	1830	White dazzling	2730

MELTING POINTS OF METALS

Substance	Temperature Fahrenheit	Metal	Temperature Fahrenheit	Metal	Temperature Fahrenheit
Spermaceti	120°	Lead	625°	Silver, pure	1830°
Wax, white	154	Zinc	780	Gold coin	2156
Sulphur	239	Antimony	842	Iron cast, med	2010
Tin	442	Aluminum	1160	Steel	2550
Bismuth	510	Brass	1650	Wrought-iron	2910



U. S. BATTLE SHIP "NEBRASKA"

BABCOCK & WILCOX BOILERS, 19,000 INDICATED HORSE-POWER

EFFICIENCY—USE OF THE COAL CALORIMETER



THE term "efficiency," specifically applied to a steam boiler, refers to the proportional amount of heat which is taken from the available supply in the fuel and transferred to the steam generated. In the case of an engine, the efficiency is determined by the amount of heat taken from the steam and transformed into useful work.

The efficiency of an entire plant, which includes both engine and boiler and all auxiliary machinery, embodying all their combined efficiencies, appears as the amount of work which can be developed by the engine for each unit of fuel consumed in the furnaces. It is evident, therefore, that if a poor engine be installed, the efficiency of the plant as a whole will be low, notwithstanding a highly efficient boiler, and *vice versa*; and the same thing will also be true, even with a first-class engine and boiler, provided much heat is wasted in the auxiliary machinery. A statement of the efficiency of a plant, therefore, indicates but little, unless something is known of its general design and the type of its various parts.

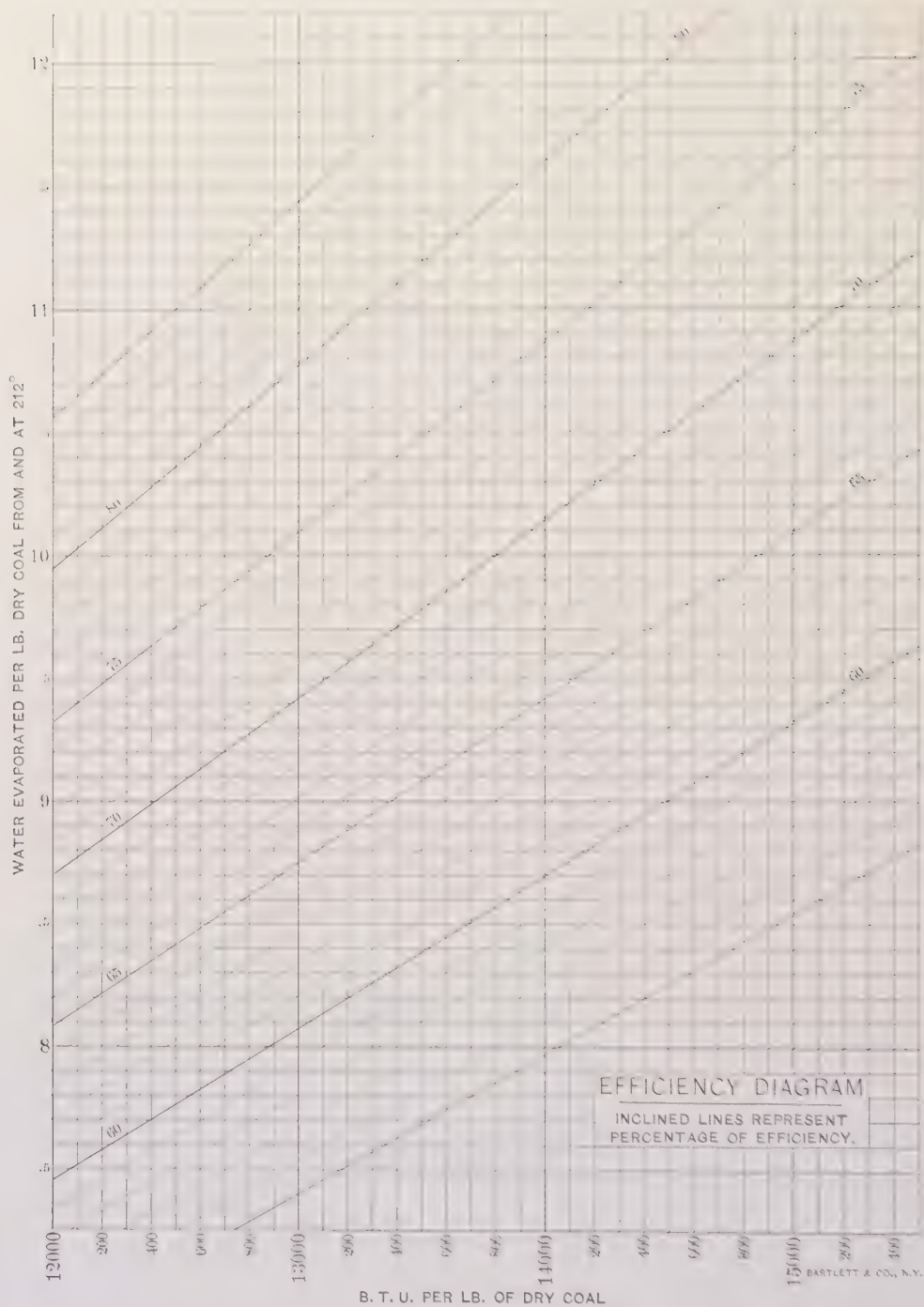
Efficiency is best expressed as a *percentage* of the total heat supplied.

Enough is known of the properties of the steam itself to make the calculation of engine efficiency an easy matter in connection with a careful test, but, in the case of the boiler, the available heat being in the coal, the proposition is of an entirely different character, and a separate test, in addition to that of the boiler, becomes necessary in order to determine the amount of heat that has been supplied by the combustion of the fuel. In fact, so difficult has this accurate determination of the heat value of coal been found, that engineers with any desire to avoid setting up false standards have until recently considered it best to make no report whatever on this point rather than to put forth unreliable or doubtful figures.

Still, without a determination of efficiency, we are left to flounder in a sea of ignorance where the only things that keep afloat our desires for comparison, are cut and dried assumptions that nine times out of ten have no counterpart in fact.

What right have we to assume that the Ohio coal, or Western Pennsylvania slack, burned under the boilers of the large ore-carrying vessels of the Great Lakes, is the same or equivalent to the Welsh or the Cumberland coal used by the transatlantic flyers? And yet, that is exactly what we do when we compare the 1.6 pounds of coal per indicated horse-power of the transatlantic service with the 1.8 pounds of the Lake practice, to the disparagement of the latter.

As a matter of fact, the best ships of that remarkable fleet of grain and ore carriers on the Lakes equal or even exceed in the matter of efficiency the larger units of the ocean greyhounds. But, it is only in the light of a reliable



EXAMPLE: Suppose it is shown by a boiler test that 10.4 pounds of water are evaporated *from and at 212* for each pound of dry coal consumed; and that the coal, tested in a Mahler Calorimeter, is found to contain 13,400 B. T. U. per pound. To determine the efficiency, find the intersection of the vertical line 13,400 with the horizontal line 10.4. This falls on the inclined line 75, showing the efficiency of the boiler to be 75 per cent.

coal calorimeter that we are able to recognize such facts as these, and to realize that without such data, terms like "*coal burned per indicated horse-power*," and "*water evaporated per pound of coal*" mean practically nothing when used as a basis for comparison.

The method of determining the heat value of fuel that at once appealed to pioneers in this work, was the burning of a sample of the fuel in a vessel surrounded by water, and, by measuring the rise in temperature of the water, estimate the heat units evolved during the combustion.

The two principal sources of error encountered were: incomplete combustion, and the liability of some of the products of combustion to escape without giving up all their heat to the water. These two objections prevail to-day in many forms of coal calorimeters, and, added to the fact that oftentimes insufficient precaution is taken to calculate radiation losses, serve to promulgate reports of very low calorific values for coal and very high percentages of boiler efficiency.

The form of calorimeter best adapted to overcome these difficulties is that designed by M. Berthelot, in which the combustion takes place in an atmosphere of oxygen gas tightly enclosed in a metal bomb which is itself submerged in water of known weight. The sample of coal to be tested (the calorimeter is equally well adapted to liquid or gaseous fuels) is finely powdered, weighed, and suspended, in the center of the bomb, in a small platinum dish or pan, after which the cover of the bomb is screwed on and oxygen gas pumped in through a valve at the top; a pressure of 20 to 25 atmospheres being used to insure there being a large excess of oxygen when the combustion takes place.

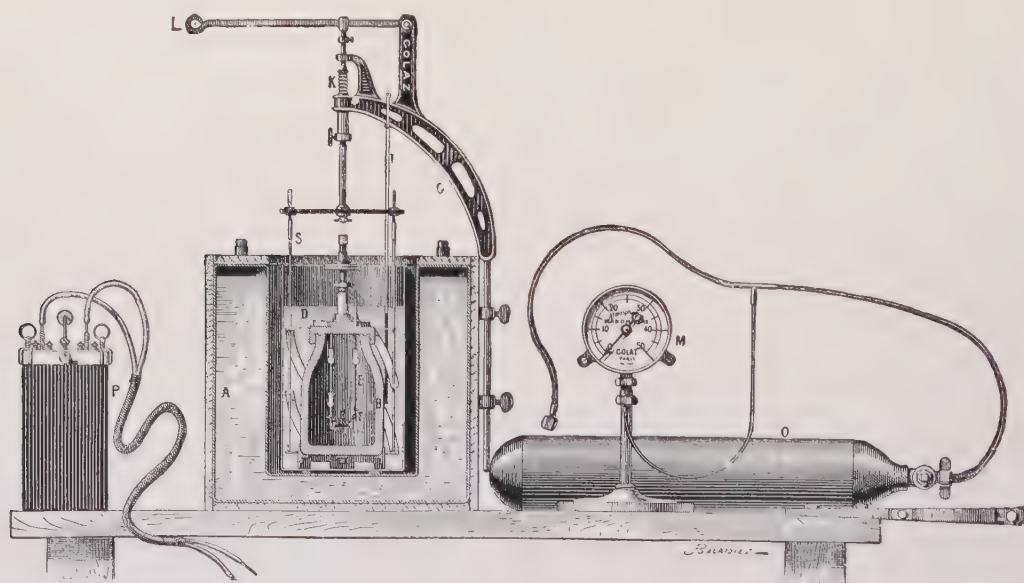
The bomb is then placed in the water, which is constantly stirred, until the whole apparatus comes to the same temperature, and enough readings are taken from the thermometer placed in the water to establish the rate of radiation under the conditions existing before combustion. It is well to have the water at the same temperature of the room, or slightly above.

When all is ready to start the combustion, an electric current is passed through a very fine iron wire which has previously been suspended from terminals inside the bomb in such a way as to touch the coal. On the passage of the current, the wire instantly fuses and ignites the coal, which, owing to the atmosphere of oxygen, burns rapidly and completely, giving up its heat to the walls of the bomb, which in turn give it up to the water. The rise in temperature of the water is carefully noted, the observations being continued until after the whole comes to the same temperature and begins to cool, and the rate of cooling is established. The thermometer used is graduated in fiftieths of a degree centigrade, and can be read to one-half of a hundredth of a degree. In this way the loss by radiation during the combustion may readily be determined and the proper allowance made. The combustion is always complete, and no loss of heat occurs from escaping gases, for the reason that the gases do not escape until after the whole operation is finished and the bomb is opened.

The bomb calorimeter, as designed by Berthelot, however, is exceedingly expensive, and it remained for M. Mahler to redesign this instrument, replacing the interior shell of platinum by a coating of enamel and otherwise improving and cheapening the construction so that the bomb calorimeter in its new form was brought within reach of the industrial world.

The accompanying cut shows the Mahler apparatus in all its essential details. The mode of operation is identical with that explained above, and all the advantages claimed for the Berthelot bomb are true of the Mahler.

Notwithstanding the fact that the Mahler calorimeter is far more expensive than many other types, the principle of the operation and the facility with which it can be made to give trustworthy determinations of the heating value of fuels, led to its selection as the best instrument for this work by the committee of the American Society of Mechanical Engineers, which drew up the 1899 code relative to a standard method of conducting steam boiler trials. It therefore stands as the representative coal calorimeter of the day.



CALORIMETER OF M. PIERRE MAHLER FOR DETERMINING THE HEATING VALUE OF FUELS

EXPLANATION: A—Water jacket to diminish radiation. B—Steel bomb, lined with enamel. C—Platinum pan for coal. D—Calorimeter containing weighed water. E—Electrode. F—Fuse wire. G—Support for agitator and thermometer. K—Spring and screw for revolving agitator. L—Lever of agitator. M—Pressure gauge. O—Oxygen cylinder. P—Electric battery. S—Agitator. T—Thermometer.

STEAM—PROPERTIES AND LAWS OF GENERATION



WHEN water is converted into steam it has first to be heated to a certain definite temperature which is called the boiling point. This temperature equals 212 degrees Fahrenheit for the ordinary pressure of the atmosphere (14.7 pounds above vacuum); but as the pressure is increased the boiling point increases, although at a decreasing ratio, until at 500 pounds above vacuum it equals 466.57 degrees Fahrenheit. As the water rises in temperature, it absorbs heat at the rate of one B. T. U. for each degree Fahrenheit. This is known as the heat of the liquid, or sensible heat, as it may be shown by means of a thermometer.

After reaching the boiling point, the further addition of heat transforms the water into steam without increasing its temperature. The heat thus absorbed is called the heat of vaporization, or "latent heat," and cannot be shown by any instrument for measuring temperatures. The latent heat decreases as the pressure increases, it being about 966 British thermal units per pound at atmospheric pressure, and about 780 at 500 pounds pressure above vacuum.

It will be seen, therefore, that the temperature of steam normal to its pressure, is the same as the water at the boiling point, and also that the total heat in steam consists of two parts; first, the heat contained in the liquid at the boiling point, and second, the heat of vaporization. Or, in other words, the *total heat* is the sum of the sensible heat and the latent heat.

The total heat increases slightly as the pressure increases, being 1146.6 British thermal units per pound at atmospheric pressure, and 1224.2 British thermal units at 500 pounds.

The density of steam increases with the pressure, and varies as the 17th root of the 16th power. Its weight per cubic foot may be found by the formula $w = .003027p^{.941}$, where p = the pressure above vacuum. The results are correct within $\frac{1}{2}$ per cent. up to 250 pounds pressure.

Saturated steam cannot be cooled except by lowering its pressure, any cooling effect being compensated for by some of the steam being condensed and giving up its latent heat. Neither can steam in direct contact with water be heated above the normal temperature corresponding to its pressure, providing there is an opportunity for free transference of heat; the only effect of the addition of more heat being to evaporate more water. If there is no outlet for the additional steam formed, both the pressure and the temperature will be increased, and the amount of heat absorbed per pound in thus increasing the temperature 1 degree Fahrenheit will equal .305 B. T. U. This is known as the specific heat of *saturated* steam. When steam is removed from contact with water, it may be heated above the normal temperature corresponding to



STEAM PACKET "RAINIER"

OWNERS: POLLARD & DODGE, SAN FRANCISCO, CAL. BABCOCK & WILCOX BOILERS, 900 INDICATED HORSE-POWER

PROPERTIES OF SATURATED STEAM

(Partly from C. H. Peabody's tables)

Pressure above Vacuum	Temperature Deg. Fahr.	Heat of Liquid above 32° F.	Latent Heat above 32° F.	Total Heat above 32° F.	Density Weight per Cu. Ft.	Pressure above Vacuum	Temperature Deg. Fahr.	Heat of Liquid above 32° F.	Latent Heat above 32° F.	Total Heat above 32° F.	Density Weight per Cu. Ft.
2	126.3	94.4	1026.1	1120.5	0.00576	172	369.2	341.5	853.1	1194.6	0.3778
4	153.1	121.4	1007.2	1128.6	0.01107	174	370.2	342.5	852.3	1194.8	0.3820
6	170.1	138.6	995.2	1133.8	0.01622	176	371.1	343.5	851.6	1195.1	0.3862
8	182.9	151.5	986.2	1137.7	0.02125	178	372.1	344.4	851.0	1195.4	0.3904
10	193.3	161.9	979.0	1140.9	0.02621	180	373.0	345.4	850.3	1195.7	0.3945
12	202.0	170.7	972.9	1143.6	0.03111	182	373.9	346.4	849.6	1196.0	0.3987
14	209.6	178.3	967.5	1145.8	0.03600	184	374.8	347.3	848.9	1196.2	0.4029
14.7	212.0	180.9	965.7	1146.6	0.03760	186	375.7	348.2	848.3	1196.5	0.4070
16	216.3	185.1	962.8	1147.9	0.04067	188	376.6	349.2	847.6	1196.8	0.4111
18	222.4	191.3	958.5	1149.8	0.04547	190	377.4	350.1	847.0	1197.1	0.4153
20	228.0	196.9	954.6	1151.5	0.05023	192	378.3	351.0	846.3	1197.3	0.4194
22	233.1	202.0	951.0	1153.0	0.05495	194	379.2	351.9	845.7	1197.6	0.4236
24	237.8	206.8	947.6	1154.4	0.05966	196	380.0	352.8	845.0	1197.8	0.4278
26	242.2	211.2	944.6	1155.8	0.06432	198	380.9	353.7	844.4	1198.1	0.4318
28	246.4	215.4	941.7	1157.1	0.06899	200	381.7	354.6	843.8	1198.4	0.4359
30	250.3	219.4	938.9	1158.3	0.07360	202	382.6	355.4	843.2	1198.6	0.4399
32	254.0	223.1	936.3	1159.4	0.07821	204	383.4	356.3	842.6	1198.9	0.4441
34	257.5	226.7	933.7	1160.4	0.08280	206	384.2	357.2	841.9	1199.1	0.4482
36	260.9	230.0	931.5	1161.5	0.08736	208	385.1	358.0	841.4	1199.4	0.4524
38	264.1	233.3	929.2	1162.5	0.09191	210	385.9	358.9	840.7	1199.6	0.4565
40	267.1	236.4	927.0	1163.4	0.09644	212	386.7	359.7	840.2	1199.9	0.4607
42	270.1	239.3	925.0	1164.3	0.1009	214	387.5	360.6	839.5	1200.1	0.4648
44	272.9	242.2	923.0	1165.2	0.1054	216	388.3	361.4	839.0	1200.4	0.4690
46	275.7	245.0	921.0	1166.0	0.1099	218	389.1	362.2	838.4	1200.6	0.4731
48	278.3	247.6	919.2	1166.8	0.1144	220	389.8	363.0	837.8	1200.8	0.4772
50	280.9	250.2	917.4	1167.6	0.1188	222	390.6	363.9	837.2	1201.1	0.4813
52	283.3	252.7	915.7	1168.4	0.1233	224	391.4	364.7	836.6	1201.3	0.4855
54	285.7	255.1	914.0	1169.1	0.1277	226	392.2	365.5	836.1	1201.6	0.4896
56	288.1	257.5	912.3	1169.8	0.1321	228	392.9	366.3	835.5	1201.8	0.4939
58	290.3	259.7	910.8	1170.5	0.1366	230	393.7	367.1	834.9	1202.0	0.4979
60	292.5	261.9	909.3	1171.2	0.1409	232	394.5	367.9	834.3	1202.2	0.5021
62	294.7	264.1	907.7	1171.8	0.1453	234	395.2	368.6	833.9	1202.5	0.5062
64	296.7	266.2	906.2	1172.4	0.1497	236	395.9	369.4	833.3	1202.7	0.5103
66	298.8	268.3	904.7	1173.0	0.1541	238	396.7	370.2	832.7	1202.9	0.5144
68	300.8	270.3	903.3	1173.6	0.1584	240	397.4	371.0	832.2	1203.2	0.5186
70	302.7	272.2	902.1	1174.3	0.1628	242	398.1	371.7	831.7	1203.4	0.5226
72	304.6	274.1	900.8	1174.9	0.1671	244	398.9	372.5	831.1	1203.6	0.5268
74	306.5	276.0	899.4	1175.4	0.1714	246	399.6	373.2	830.6	1203.8	0.5311
76	308.3	277.8	898.2	1176.0	0.1757	248	400.3	374.0	830.0	1204.0	0.5353
78	310.1	279.6	896.9	1176.5	0.1801	250	401.0	374.7	829.5	1204.2	0.5393
80	311.8	281.4	895.6	1177.0	0.1843	252	401.7	375.4	829.1	1204.5	0.5433
82	313.5	283.2	894.4	1177.6	0.1886	254	402.4	376.2	828.5	1204.7	0.5475
84	315.2	285.0	893.1	1178.1	0.1930	256	403.1	376.9	828.0	1205.0	0.5517
86	316.8	286.7	891.9	1178.6	0.1973	258	403.8	377.6	827.5	1205.1	0.5559
88	318.5	288.4	890.7	1179.1	0.2016	260	404.5	378.4	826.9	1205.3	0.5601
90	320.0	290.0	889.6	1179.6	0.2058	262	405.2	379.1	826.4	1205.5	0.5642
92	321.6	291.6	888.4	1180.0	0.2101	264	405.8	379.8	825.9	1205.7	0.5684
94	323.1	293.2	887.3	1180.5	0.2144	266	406.5	380.5	825.4	1205.9	0.5726
96	324.6	294.8	886.2	1181.0	0.2186	268	407.2	381.2	824.9	1206.1	0.5767
98	326.1	296.4	885.0	1181.4	0.2229	270	407.9	381.9	824.4	1206.3	0.5809
100	327.6	297.9	884.0	1181.9	0.2271	272	408.5	382.6	823.9	1206.5	0.5850
102	329.0	299.4	882.9	1182.3	0.2314	274	409.2	383.3	823.4	1206.7	0.5892
104	330.4	300.9	881.8	1182.7	0.2356	276	409.8	384.0	822.9	1206.9	0.5934
106	331.8	302.3	880.8	1183.1	0.2399	278	410.5	384.6	822.5	1207.1	0.5976
108	333.2	303.8	879.8	1183.6	0.2441	280	411.1	385.3	822.0	1207.3	0.602
110	334.6	305.2	878.8	1184.0	0.2484	282	411.8	386.0	821.5	1207.5	0.606
112	335.9	306.6	877.8	1184.4	0.2526	284	412.4	386.6	821.1	1207.7	0.610
114	337.2	308.0	876.8	1184.8	0.2568	286	413.0	387.3	820.6	1207.9	0.614
116	338.5	309.4	875.8	1185.2	0.2610	288	413.7	388.0	820.1	1208.1	0.618
118	339.8	310.7	874.9	1185.6	0.2653	290	414.3	388.6	819.7	1208.3	0.622
120	341.1	312.0	874.0	1186.0	0.2695	292	414.9	389.3	819.2	1208.5	0.627
122	342.3	313.3	873.0	1186.3	0.2736	294	415.6	390.0	818.7	1208.7	0.631
124	343.5	314.6	872.1	1186.7	0.2779	296	416.2	390.6	818.3	1208.9	0.635
126	344.7	315.9	871.2	1187.1	0.2820	298	416.8	391.3	817.8	1209.1	0.639
128	345.9	317.1	870.3	1187.4	0.2862	300	417.4	391.9	817.4	1209.3	0.644
130	347.1	318.4	869.4	1187.8	0.2904	302	418.0	392.5	816.9	1209.4	0.648
132	348.3	319.6	868.6	1188.2	0.2946	304	418.6	393.2	816.4	1209.6	0.652
134	349.5	320.8	867.7	1188.5	0.2988	306	419.2	393.8	816.0	1209.8	0.656
136	350.6	322.0	866.9	1188.9	0.3030	308	419.8	394.4	815.6	1210.0	0.660
138	351.7	323.2	866.0	1189.2	0.3072	310	420.4	395.0	815.2	1210.2	0.664
140	352.9	324.4	865.1	1189.5	0.3113	312	421.0	395.7	814.7	1210.4	0.668
142	354.0	325.6	864.3	1189.9	0.3155	314	421.6	396.3	814.2	1210.5	0.673
144	355.1	326.7	863.5	1190.2	0.3197	316	422.2	396.9	813.8	1210.7	0.677
146	356.1	327.8	862.8	1190.6	0.3239	318	422.8	397.5	813.4	1210.9	0.681
148	357.2	328.9	862.0	1190.9	0.3280	320	423.4	398.1	813.0	1211.1	0.685
150	358.3	330.0	861.2	1191.2	0.3321	322	424.0	398.7	812.5	1211.2	0.690
152	359.3	331.1	860.4	1191.5	0.3363	324	424.5	399.3	812.1	1211.4	0.694
154	360.3	332.2	859.6	1191.8	0.3405	326	425.1	399.9	811.7	1211.6	0.698
156	361.4	333.3	858.9	1192.2	0.3447	328	425.7	400.5	811.3	1211.8	0.702
158	362.4	334.3	858.2	1192.5	0.3488	330	426.2	401.1	810.8	1211.9	0.707
160	363.4	335.4	857.4	1192.8	0.3530	332	426.8	401.7	810.4	1212.1	0.711
162	364.4	336.4	856.7	1193.1	0.3572	334	427.3	402.3	810.0	1212.2	0.715
164	365.4	337.5	855.9	1193.4	0.3614	336	427.9	402.9	809.6	1212.4	0.719
166	366.4	338.5	855.2	1193.7	0.3655	338	428.4	403.5	809.2	1212.5	0.723
168	367.3	339.5	854.5	1194.0	0.3695	340	428.9	404.1	808.8	1212.6	0.727
170	368.3	340.5	853.8	1194.3	0.3737	342	429.4	404.7	808.4	1212.7	0.731



LAKE S. S. "SUPERIOR CITY"

450 FEET LONG, 50 FEET BEAM, 28 FEET DEEP, LOADED DRAFT, 17 FEET. THE ABOVE ILLUSTRATION SHOWS THIS VESSEL LOADED WITH THE LARGEST CARGO OF GRAIN (1899) THAT HAD EVER BEEN CARRIED ON THE GREAT LAKES, 7642 TONS. OWNERS: ZENITH TRANSIT CO.

its pressure. It is then called superheated, and the specific heat of *superheated* steam is .475.

The table on page 91 gives the properties of saturated steam at various pressures. It should be noted in using this table that the pressure given is *absolute pressure*, so that 15 pounds (or more exactly 14.7) should be added to the reading of the gauge.

Pressures below the atmosphere, or partial vacuum, are often expressed in inches (of mercury). The following table gives the temperature and pressure of steam for each half inch.

TEMPERATURE AND PRESSURE OF STEAM FOR EACH ½" OF VACUUM

(Calculated from C. H. Peabody's tables)

Inches of Vacuum	Absolute Pressure Lbs. per Sq. In.	Tempera- ture Degrees Fahr.	Inches of Vacuum	Absolute Pressure Lbs. per Sq. In.	Tempera- ture Degrees Fahr.	Inches of Vacuum	Absolute Pressure Lbs. per Sq. In.	Tempera- ture Degrees Fahr.
0	14.697	212.00	10	9.785	192.23	20	4.873	161.25
½	14.451	211.15	10½	9.539	191.03	20½	4.628	159.09
1	14.206	210.29	11	9.294	189.81	21	4.382	156.83
1½	13.960	209.42	11½	9.048	188.57	21½	4.136	154.46
2	13.715	208.54	12	8.803	187.30	22	3.891	151.97
2½	13.469	207.64	12½	8.557	186.00	22½	3.755	149.34
3	13.223	206.73	13	8.311	184.66	23	3.410	146.55
3½	12.978	205.80	13½	8.066	183.29	23½	3.164	143.59
4	12.732	204.86	14	7.820	181.88	24	2.918	140.42
4½	12.487	203.91	14½	7.575	180.44	24½	2.673	137.01
5	12.241	202.94	15	7.329	178.96	25	2.427	133.32
5½	11.995	201.95	15½	7.084	177.44	25½	2.172	129.31
6	11.750	200.95	16	6.838	175.87	26	1.926	124.89
6½	11.504	199.93	16½	6.592	174.26	26½	1.680	119.94
7	11.259	198.89	17	6.347	172.59	27	1.435	114.34
7½	11.013	197.83	17½	6.101	170.86	27½	1.189	107.84
8	10.767	196.75	18	5.856	169.07	28	0.944	100.05
8½	10.522	195.65	18½	5.610	167.23	28½	0.698	90.24
9	10.276	194.53	19	5.364	165.31	29	0.453	76.80
9½	10.031	193.39	19½	5.119	163.32	29½	0.207	54.21

WATER—THE MEASUREMENT OF HEAT

Water has a greater capacity for absorbing heat than any other known substance—bromine and hydrogen excepted. For this reason and from the fact that it is so commonly found in nature, and can be easily handled in experimental work, it has been adopted as the standard substance for measuring the quantity of heat.

Two distinct heat units are used in practice—calories and British thermal units. The latter, usually designated by the letters B. T. U., is the quantity of heat required to raise the temperature of one pound of water, at or near the freezing point, one degree Fahrenheit. The calorie is the quantity required to



STEAM PACKET "CITY OF NANAIMO" (PUGET SOUND)

OWNERS: ESQUIMALT & NANAIMO RAILWAY CO., VICTORIA, B. C. BABCOCK & WILCOX BOILERS, 750 INDICATED HORSE-POWER

raise a kilogram of water one degree centigrade, and is equal to 3.958 British thermal units.

The heat-absorbing capacity, or, as it is called, the specific heat of water, is not exactly constant for all temperatures, but after decreasing very slightly, again increases, and in a gradually increasing ratio, as the temperature is increased.

The accompanying table shows the number of British thermal units that will be absorbed by one pound of water, when heated from 32 degrees to various temperatures below 212 degrees.

WATER BETWEEN 32 AND 212 DEGREES FAHRENHEIT

Temper- ature Fahr.	Heat Units per Lb.	Weight, Lbs. per Cubic Ft.	Temper- ature Fahr.	Heat Units per Lb.	Weight Lbs. per Cubic Ft.	Temper- ature Fahr.	Heat Units per Lb.	Weight, Lbs. per Cubic Ft.	Temper- ature Fahr.	Heat Units per Lb.	Weight, Lbs. per Cubic Ft.
32°	0.00	62.42	110°	78.00	61.89	145°	113.26	61.28	179°	147.54	60.57
35	3.02	62.42	112	80.00	61.86	146	114.27	61.26	180	148.54	60.55
40	8.06	62.42	113	81.01	61.84	147	115.28	61.24	181	149.55	60.53
45	13.08	62.42	114	82.02	61.83	148	116.29	61.22	182	150.56	60.50
50	18.10	62.41	115	83.02	61.82	149	117.30	61.20	183	151.57	60.48
52	20.11	62.40	116	84.03	61.80	150	118.30	61.18	184	152.58	60.46
54	22.11	62.40	117	85.04	61.78	151	119.31	61.16	185	153.58	60.44
56	24.11	62.39	118	86.05	61.77	152	120.32	61.14	186	154.59	60.41
58	26.12	62.38	119	87.06	61.75	153	121.33	61.12	187	155.60	60.39
60	28.12	62.37	120	88.06	61.74	154	122.34	61.10	188	156.61	60.37
62	30.12	62.36	121	89.07	61.72	155	123.34	61.08	189	157.62	60.34
64	32.12	62.35	122	90.08	61.70	156	124.35	61.06	190	158.62	60.32
66	34.12	62.34	123	91.09	61.68	157	125.36	61.04	191	159.63	60.29
68	36.12	62.33	124	92.10	61.67	158	126.37	61.02	192	160.63	60.27
70	38.11	62.31	125	93.10	61.65	159	127.38	61.00	193	161.64	60.25
72	40.11	62.30	126	94.11	61.63	160	128.38	60.98	194	162.65	60.22
74	42.11	62.28	127	95.12	61.61	161	129.39	60.96	195	163.66	60.20
76	44.11	62.27	128	96.13	61.60	162	130.40	60.94	196	164.66	60.17
78	46.10	62.25	129	97.14	61.58	163	131.41	60.92	197	165.67	60.15
80	48.09	62.23	130	98.14	61.56	164	132.42	60.90	198	166.68	60.12
82	50.08	62.21	131	99.15	61.54	165	133.42	60.87	199	167.69	60.10
84	52.07	62.19	132	100.16	61.52	166	134.43	60.85	200	168.70	60.07
86	54.06	62.17	133	101.17	61.51	167	135.44	60.83	201	169.70	60.05
88	56.05	62.15	134	102.18	61.49	168	136.45	60.81	202	170.71	60.02
90	58.04	62.13	135	103.18	61.47	169	137.46	60.79	203	171.72	60.00
92	60.03	62.11	136	104.19	61.45	170	138.46	60.77	204	172.73	59.97
94	62.02	62.09	137	105.20	61.43	171	139.47	60.75	205	173.74	59.95
96	64.01	62.07	138	106.21	61.41	172	140.48	60.73	206	174.74	59.92
98	66.01	62.05	139	107.22	61.39	173	141.49	60.70	207	175.75	59.89
100	68.01	62.02	140	108.22	61.37	174	142.50	60.68	208	176.76	59.87
102	70.00	62.00	141	109.23	61.36	175	143.50	60.66	209	177.77	59.84
104	72.00	61.97	142	110.24	61.34	176	144.51	60.64	210	178.78	59.82
106	74.00	61.95	143	111.25	61.32	177	145.52	60.62	211	179.78	59.79
108	76.00	61.92	144	112.26	61.30	178	146.53	60.59	212	180.79	59.76

There are four notable temperatures for pure water, viz.:

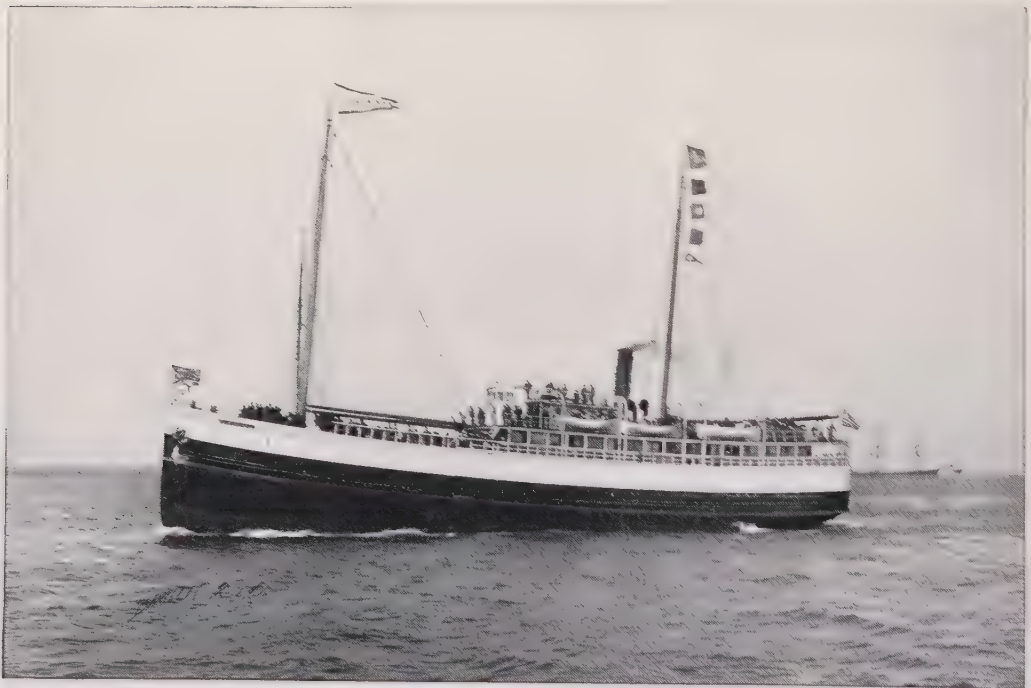
1. Freezing point at sea level, 32° F. Weight per cu. ft., 62.418 lb.; per cu. in., .03612 lb.
2. Point of maximum density, 39.1° F. Weight per cu. ft., 62.425 lb.; per cu. in., .036125 lb.
3. British standard for specific gravity, 62° F. Weight per cu. ft., 62.355 lb.; per cu. in., .03608 lb.
4. Boiling point at sea level, 212° F. Weight per cu. ft., 59.760 lb.; per cu. in., .03458 lb.

A United States standard gallon holds 231 cubic inches, and 8 1/3 pounds of water at 62 degrees Fahrenheit.

A British imperial gallon holds 277.274 cubic inches, and 10 pounds of water at 62 degrees Fahrenheit.

Sea water (average) has a specific gravity of 1.028, boils at 213.2 degrees F., and weighs 64 pounds per cubic foot at 62 degrees Fahrenheit.

A pressure of 1 pound per square inch is exerted by a column of water 2.3093 feet, or 27.71 inches high, at 62 degrees Fahrenheit.



STEAM PACKET "SANTA ANA"

OWNERS, A. W. BEADLE & Co., SAN FRANCISCO, CAL. BARCOCK & WILCOX BOILERS, 700
INDICATED HORSE-POWER

EQUIVALENT EVAPORATION FROM AND AT 212° F.



FOR purposes of comparison, it is usual to reduce the *actual* evaporative results obtained in practice, to a common standard, known as "*equivalent evaporation from and at 212.*" This means that the temperature of the feed water is supposed to be *at 212 degrees*, and that the evaporation takes place at atmospheric pressure, or *from 212 degrees*, the equivalent amount of water being calculated which would be evaporated under such conditions.

In both cases the heat imparted to the water is the same, and in order to find the "*equivalent evaporation,*" it is only necessary to find the amount of heat *actually absorbed* by the water in being converted into steam in the boiler, and divide this by 965.7, the latent heat of steam at atmospheric pressure, which is the heat required to evaporate one pound of water "from and at 212 degrees."

For example, suppose that 3000 pounds of water are evaporated per hour at a pressure of 70 pounds, the feed water entering the boiler at 100 degrees Fahrenheit. By reference to the steam tables, it is found that steam at 70 pounds gauge pressure (84.7 absolute) contains 1178.3 British thermal units per pound above 32 degrees; and from the table for heat in the water, it is found that each pound of water at 100 degrees Fahrenheit contains 68.01 British thermal units above 32 degrees. The boiler will therefore have to impart to each pound of steam generated, the difference between these quantities, or (1178.3 — 68.01) 1110.29 British thermal units. This amount, divided by 965.7, gives 1.1497, or, say, 1.15. That is, the same amount of heat imparted to one pound of water at 100 degrees Fahrenheit, in converting it into steam at 70 pounds pressure, would evaporate 1.15 pounds

FACTORS OF EVAPORATION.

From the Table, computed by Mr. Geo. A. Powell.

Temp' of Feed Water, Deg. Fahr.	STEAM PRESSURE IN GAUGE																			
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
32	1.214	1.216	1.220	1.222	1.225	1.227	1.229	1.231	1.232	1.234	1.236	1.237	1.239	1.240	1.241	1.243	1.244	1.245	1.246	1.247
40	1.206	1.209	1.212	1.214	1.216	1.219	1.220	1.222	1.224	1.226	1.227	1.229	1.230	1.232	1.233	1.234	1.235	1.237	1.237	1.239
50	1.195	1.197	1.201	1.204	1.206	1.208	1.210	1.212	1.214	1.215	1.217	1.218	1.220	1.221	1.223	1.224	1.225	1.226	1.227	1.229
60	1.185	1.188	1.191	1.193	1.196	1.198	1.200	1.202	1.204	1.205	1.207	1.208	1.210	1.211	1.213	1.214	1.215	1.216	1.217	1.219
70	1.175	1.178	1.180	1.183	1.185	1.187	1.189	1.191	1.193	1.194	1.196	1.197	1.199	1.200	1.202	1.203	1.204	1.205	1.206	1.207
80	1.164	1.167	1.169	1.173	1.175	1.177	1.179	1.181	1.183	1.184	1.186	1.187	1.189	1.190	1.192	1.193	1.194	1.195	1.196	1.197
90	1.154	1.157	1.160	1.162	1.165	1.167	1.169	1.170	1.172	1.174	1.176	1.177	1.179	1.180	1.181	1.183	1.184	1.185	1.186	1.187
100	1.144	1.147	1.150	1.152	1.154	1.156	1.158	1.160	1.162	1.164	1.165	1.167	1.168	1.169	1.171	1.172	1.173	1.174	1.175	1.176
110	1.133	1.136	1.139	1.142	1.144	1.146	1.148	1.150	1.152	1.153	1.155	1.156	1.158	1.159	1.160	1.162	1.163	1.164	1.166	1.167
120	1.123	1.126	1.129	1.131	1.133	1.136	1.138	1.139	1.141	1.143	1.145	1.146	1.147	1.149	1.150	1.151	1.153	1.154	1.155	1.156
130	1.113	1.116	1.118	1.121	1.123	1.125	1.127	1.129	1.130	1.132	1.134	1.136	1.137	1.138	1.140	1.141	1.143	1.144	1.145	1.146
140	1.102	1.105	1.108	1.110	1.113	1.115	1.117	1.119	1.120	1.122	1.124	1.125	1.127	1.128	1.130	1.131	1.133	1.134	1.135	1.136
150	1.091	1.095	1.098	1.100	1.102	1.104	1.106	1.108	1.110	1.111	1.113	1.115	1.116	1.118	1.119	1.120	1.121	1.123	1.124	1.125
160	1.081	1.084	1.087	1.090	1.092	1.094	1.096	1.098	1.100	1.101	1.103	1.104	1.106	1.107	1.109	1.110	1.111	1.112	1.113	1.114
170	1.070	1.074	1.077	1.079	1.081	1.083	1.085	1.087	1.089	1.091	1.092	1.094	1.095	1.097	1.098	1.099	1.101	1.102	1.103	1.104
180	1.060	1.063	1.066	1.069	1.071	1.073	1.075	1.077	1.079	1.080	1.082	1.083	1.085	1.086	1.088	1.089	1.090	1.091	1.093	1.094
190	1.050	1.053	1.056	1.058	1.060	1.063	1.065	1.066	1.068	1.070	1.071	1.073	1.074	1.076	1.077	1.078	1.080	1.081	1.082	1.084
200	1.039	1.043	1.045	1.048	1.050	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.064	1.065	1.067	1.068	1.069	1.071	1.072	1.073
210	1.029	1.032	1.035	1.037	1.040	1.042	1.044	1.046	1.047	1.049	1.051	1.052	1.053	1.055	1.056	1.057	1.059	1.060	1.061	1.062

from and at 212 degrees Fahrenheit ; so that 3000 pounds evaporated at actual conditions are *equivalent* to (1.15×3000) 3450 pounds from and at 212 degrees. The quantity 1.15 is called the factor of evaporation. It may be expressed by the following formula: $F = \frac{H - h}{965.7}$, in which H equals the total heat in steam above 32 degrees at boiler pressure; h equals the heat in the feed water above 32 degrees, and 965.7 equals the latent heat in steam at atmospheric pressure.

For convenient reference, the table on the preceding page gives these factors for various pressures, and temperatures of feed water.



STEAM PACKET "ROBERT DOLLAR"

OWNER: ROBERT DOLLAR, SAN FRANCISCO, CAL. BABCOCK & WILCOX BOILERS, 550 INDICATED HORSE-POWER

DRY STEAM—USE OF THE STEAM CALORIMETER



STEAM without moisture is the essential product of a well-designed steam generator. It may be saturated in quality, or superheated, but it must not be wet.

Dry steam, or, as it is called technically, saturated steam (meaning steam saturated with heat), is steam in its natural or normal condition. If any heat is added it immediately becomes superheated, and it should be noted that it cannot become superheated until it has first become dry, while if any heat is taken away from saturated steam, a portion of it is at once condensed to the form of moisture. The steam that remains, however, is itself dry, and what we know as wet steam is really a mixture of dry steam and small particles of moisture which are mechanically mixed with it and carried along in the current. The question of making dry steam, therefore, is one of properly liberating the bubbles of steam from the surrounding water so that none of the latter shall be entrained with it.

As is well known, the immediate predecessor of the water-tube boiler in marine work was the cylindrical or Scotch boiler of large diameters.

The Babcock & Wilcox boiler is built with a steam and water drum of less than four feet diameter, and herein is one of its great elements of lightness and safety. But, as a result of this smaller diameter, and consequent reduction of liberating surface, it might at first appear that the quality of the steam would be affected and that considerable moisture would be entrained. That such, however, is not the case, is shown by the following statements of prominent engineers who have obtained their knowledge from actual tests and experience with the boiler :

"The moisture in the steam is so infinitesimal as to be entirely negligible in the final results."—*Lieutenants B. C. Bryan and W. W. White, U. S. N.*

"The calorimetric experiments show the steam to have been perfectly dry."—*Chas. E. Emery, Ph. D.*

"Percentage of moisture in steam—part of 1 per cent.—.3 to .5."—*J. M. Whitham, Mem. Am. Soc. M. E.*

"At the highest rates of forcing, the moisture entrained in the steam never exceeded $\frac{1}{4}$ of 1 per cent."—*Ernest H. Peabody, Mem. Am. Soc. M. E.*

"Moisture in steam, 0.48 of 1 per cent., or practically dry."—*Robert Logan, N. A.*

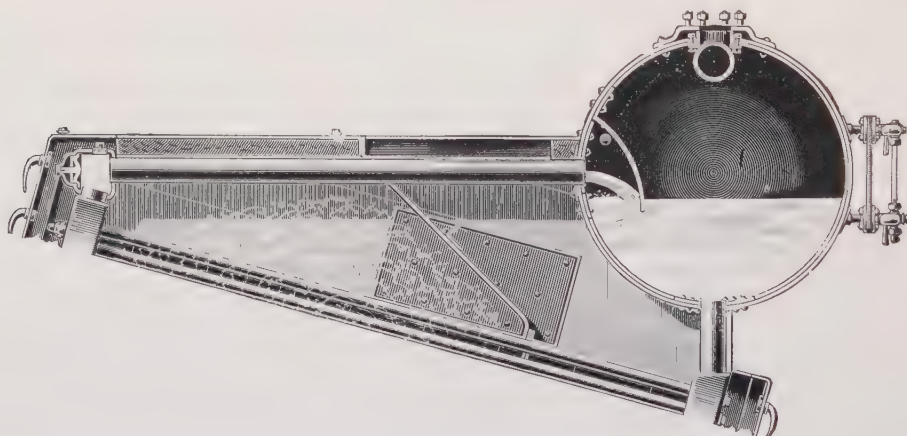
"The calorimeter showed .72 of 1 per cent. of moisture at the throttle valve, or practically dry steam."—*J. E. Denton, Prof. of Mechanical Engineering, Stevens Institute of Technology.*

In addition to this testimony, it will be convincing to many to consider that a boiler which made wet steam could scarcely attain the success the Babcock & Wilcox boiler has achieved, or stand the test of continued and varied usage.

The following experiment, made several years ago at the works of this company, serves to show the manner in which steam is separated from the water in this type of boiler, and passes in a dry state to the perforated dry pipe connected with the outlet from the drum. It also proves that the size of the drum has little to do with the dryness of the steam, and that a very small liberating surface in connection with a very little *time* is all that is needed to insure the proper liberation of the steam from the water.

In order to observe the phenomena going on inside the steam drum of a boiler in service, a peep-hole, filled with a stout piece of glass, was made in each drum-head, opposite the space between the return circulating tubes and the baffle plate. By means of an electric arc light placed at one eye piece, the interior of the drum was illuminated and the discharge of each of the circulating tubes distinctly seen.

When the boiler was steaming rapidly, with $\frac{3}{4}$ -inch air blast in the ash pit, the observations clearly showed that each of the circulating tubes was discharging against the baffle plate, with considerable velocity, a stream of solid water that filled the tube for half its diameter.



There was no spray or mist whatever, showing conclusively that the steam had entirely separated from the water during its passage through the circulating tubes, which, in this boiler, were only 50 inches long by 4 inches in diameter. As a matter of fact, the actual steam liberating surface required for the entire boiler was less than that contained in the circulating tubes, which amounted to about 15 square feet, or 1 square foot to every 100 square feet of heating surface in the boiler.

After striking the baffle plate, the water was deflected downward, mixing with the main body of water in the drum, while the steam passed around the ends of the baffle plate into the steam space in which is located the dry pipe.

The drum itself is not exposed to great heat in this type of boiler, and the water in it is not agitated in any way, so that there is no possibility of water or

spray reaching the dry pipe. In view of this experiment, it is evident that the Babcock & Wilcox marine boiler cannot furnish anything *but* dry steam.

In any ship or other installation of boilers, however, it must be remembered that after leaving the generator the steam passes at once into a system of piping, which, even if well covered, is always being more or less cooled by the surrounding air. This cooling effect necessarily condenses some of the steam, and it has often happened that samples of steam have been tested which, by accident, contain some of this condensation from the sides of the pipe. Such tests are not only manifestly unfair to the boiler, but are very misleading in their results.

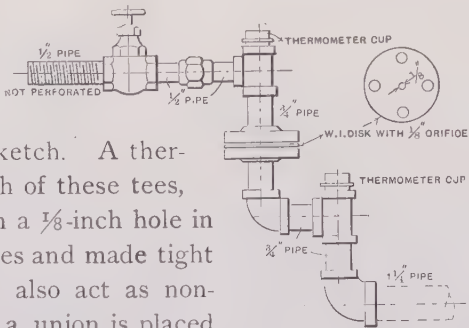
METHOD OF TESTING STEAM

The method best adapted to insure obtaining a fair sample of steam for testing, is to take it from the center of the vertical portion of the steam pipe as near the boiler as possible. Use a straight open-ended nipple, provided with a long thread on one end so that it may be screwed into the steam pipe far enough to bring the open end at or near the center of the current of steam ascending from the boiler, and as far removed as possible from the sides of the pipe, which are always coated with a thin film of moisture. Do not use perforated or slotted nipples, as they have been found to give very inaccurate results.

The throttling calorimeter, first devised by Prof. C. H. Peabody, of the Massachusetts Institute of Technology (see "Journal of Franklin Institute," August, 1888), is by far the simplest type of instrument for testing the quality of steam, and, when properly used, gives very accurate results.

There have been numerous forms of this instrument, one of the simplest being that designed by Mr. George H. Barrus, of Boston, which is described below :

Steam is taken from a $\frac{1}{2}$ -inch pipe provided with a valve, and passed through two $\frac{3}{4}$ -inch tees situated on opposite sides of a $\frac{3}{4}$ -inch flange union, substantially as shown in the accompanying sketch. A thermometer cup, or well, is screwed into each of these tees, and a piece of sheet-iron, perforated with a $\frac{1}{8}$ -inch hole in the center, is inserted between the flanges and made tight with rubber or asbestos gaskets, which also act as non-conductors of heat. For convenience, a union is placed near the valve, as shown; and the exhaust steam may be led away by a *short* $1\frac{1}{4}$ -inch pipe, shown by dotted lines. The thermometer wells are filled with mercury or heavy cylinder oil, and the whole instrument, from the steam main to the $1\frac{1}{4}$ -inch pipe, is well covered with hair felt.



Great care must be taken that the $\frac{1}{8}$ -inch orifice does not become choked with dirt, and that no leaks occur, especially at the sheet-iron disc, also that the



U. S. S. "DENVER"
SIX BABCOCK & WILCOX BOILERS, 4500 HORSE-POWER

exhaust pipe does not produce any back pressure below the flange. Place a thermometer in each cup, and, opening the $\frac{1}{2}$ -inch valve wide, let steam flow through the instrument for ten or fifteen minutes; then take frequent readings on the two thermometers and the boiler gauge, say at intervals of one minute.

The throttling calorimeter depends on the principle that dry steam when expanded from a higher to a lower pressure, without doing external work, becomes superheated, the amount of superheat depending on the two pressures. If, however, some moisture be present in the steam, this must necessarily first be evaporated, and the superheating will be proportionately less. The limit of the instrument is reached when the moisture present is sufficient to prevent any superheating.

Assuming that there is no back pressure in the exhaust, and that there is no loss of heat in passing through the instrument, the total heat in the mixture of steam and moisture before throttling, and in the superheated steam after throttling, will be the same, and will be expressed by the equation

$$H - \frac{xL}{100} = 1146.6 + .48(t - 212)$$

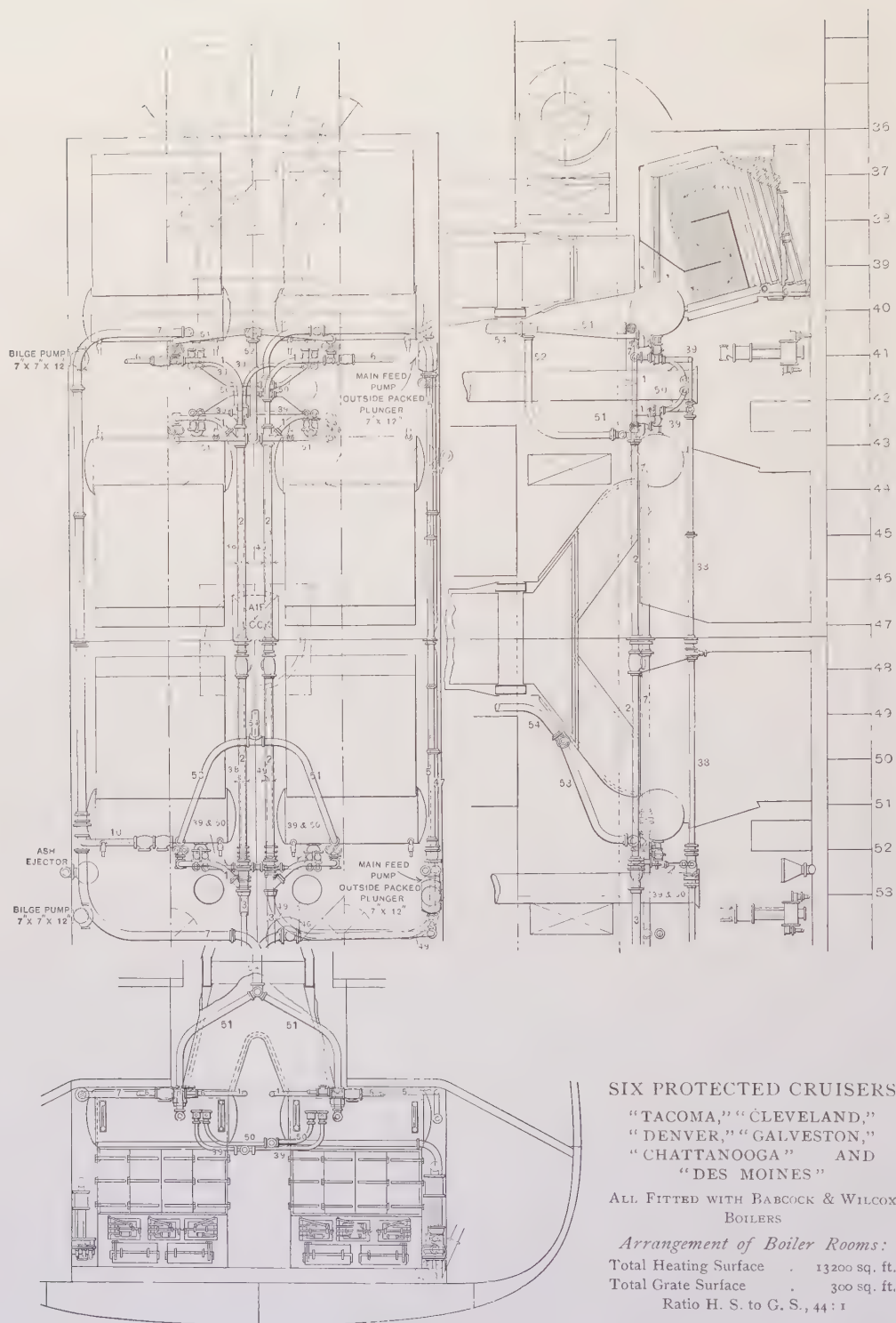
$$\text{or } x = \frac{H - 1146.6 - .48(t - 212)}{L} \times 100$$

in which x = percentage of moisture; H = total heat above 32° in the steam at boiler pressure; L = latent heat in the steam at boiler pressure; 1146.6 = total heat in the steam at atmospheric pressure; t = temperature shown by lower thermometer of calorimeter; 212 = temperature of dry steam at atmospheric pressure.

Theoretically the boiler pressure is indicated by the temperature of the upper thermometer; but, owing to radiation, etc., it is usually too low, and it is better to use the readings of the boiler gauge, if correct, or better still to have a test gauge connected on the $\frac{1}{2}$ -inch pipe supplying the calorimeter.

If the instrument be well covered, and there is as little radiating surface as possible, the above assumption that there is no loss of heat in passing through the instrument may be nearly, though never quite, correct. On the other hand it is more than likely to be very far from correct, and, to eliminate any errors of this kind, Mr. Barrus recommends a so-called "calibration" for dry steam. This, again, involves an assumption which is open to some doubt, which is that steam, when in a quiescent state, drops all its moisture and becomes dry. No other practical method, however, has been proposed, and this is, therefore, the only method used at the present time. Some engineers, however, refuse to make any calibration, but, instead, make an assumed allowance for error.

To make the calibration, close the boiler stop valve, which must be on the steam pipe beyond the calorimeter connection. Keep the steam pressure exactly the same as the average pressure during the test, for at least fifteen



SIX PROTECTED CRUISERS

"TACOMA," "CLEVELAND,"
 "DENVER," "GALVESTON,"
 "CHATTANOOGA" AND
 "DES MOINES"

ALL FITTED WITH BABCOCK & WILCOX
 BOILERS

Arrangement of Boiler Rooms:

Total Heating Surface . . . 13200 sq. ft.
 Total Grate Surface . . . 300 sq. ft.
 Ratio H. S. to G. S., 44 : 1

FRAME 42
 LOOKING FORWARD

minutes, taking readings from the two thermometers during the last five minutes. The upper thermometer should read precisely the same as during the test, and the lower thermometer should show a higher temperature; this reading of the *lower* thermometer is the calibration reading for dry steam, which we will call T .

Calculation of results, allowing for radiation by calibration method:—

$$\text{Formula, } x = \frac{.48 (T - t)}{L} \times 100$$

in which x = percentage of moisture; T = calibration reading of lower thermometer; t = test reading of lower thermometer; L = latent heat of steam at boiler pressure.

The method of taking a sample of steam from the main is of the greatest importance, and more erroneous results are due to improper connections than to any other cause. Use only a plain, open-ended nipple projecting far enough into the steam pipe to avoid collecting any condensation that may be on the sides of the pipe. Take care that no pockets exist in the steam main near the calorimeter, in which condensation can collect and run down into sampling nipple. Remember you are ascertaining the amount of moisture in the steam and not measuring the condensation on the walls of the steam piping. Make connections as short as possible.

As mentioned above, there is a limit in the range of the throttling calorimeter which varies from 2.88 per cent. at 50 pounds pressure to 7.17 per cent. at 250 pounds. When this limit is reached a small separator may be interposed between the steam main and the calorimeter, which will take out the excess of moisture. By weighing the drip from the separator and ascertaining its percentage of the steam flowing through, and adding this to the percentage of moisture then shown by the throttling calorimeter, the total moisture in the steam may be ascertained. It is seldom, however, in a well-designed boiler, that any but a throttling calorimeter becomes necessary.





S. S. "PARAGUAY"

OWNERS: INTERNATIONAL STEAMSHIP CO. BABCOCK & WILCOX BOILERS, 1500 INDICATED HORSE-POWER

ECONOMY DUE TO THE HEATING OF FEED WATER



THE importance of heating feed water before delivering it to a boiler can best be realized by considering exactly what takes place during the generation of steam. As explained on page 89, the total heat in steam consists partly of *sensible heat*, which marks the boiling point of the water, and partly of *latent heat*, which converts the water into steam. Therefore, in generating steam in a boiler, the water must first be heated to the boiling point and then enough heat added to evaporate it at the required pressure.

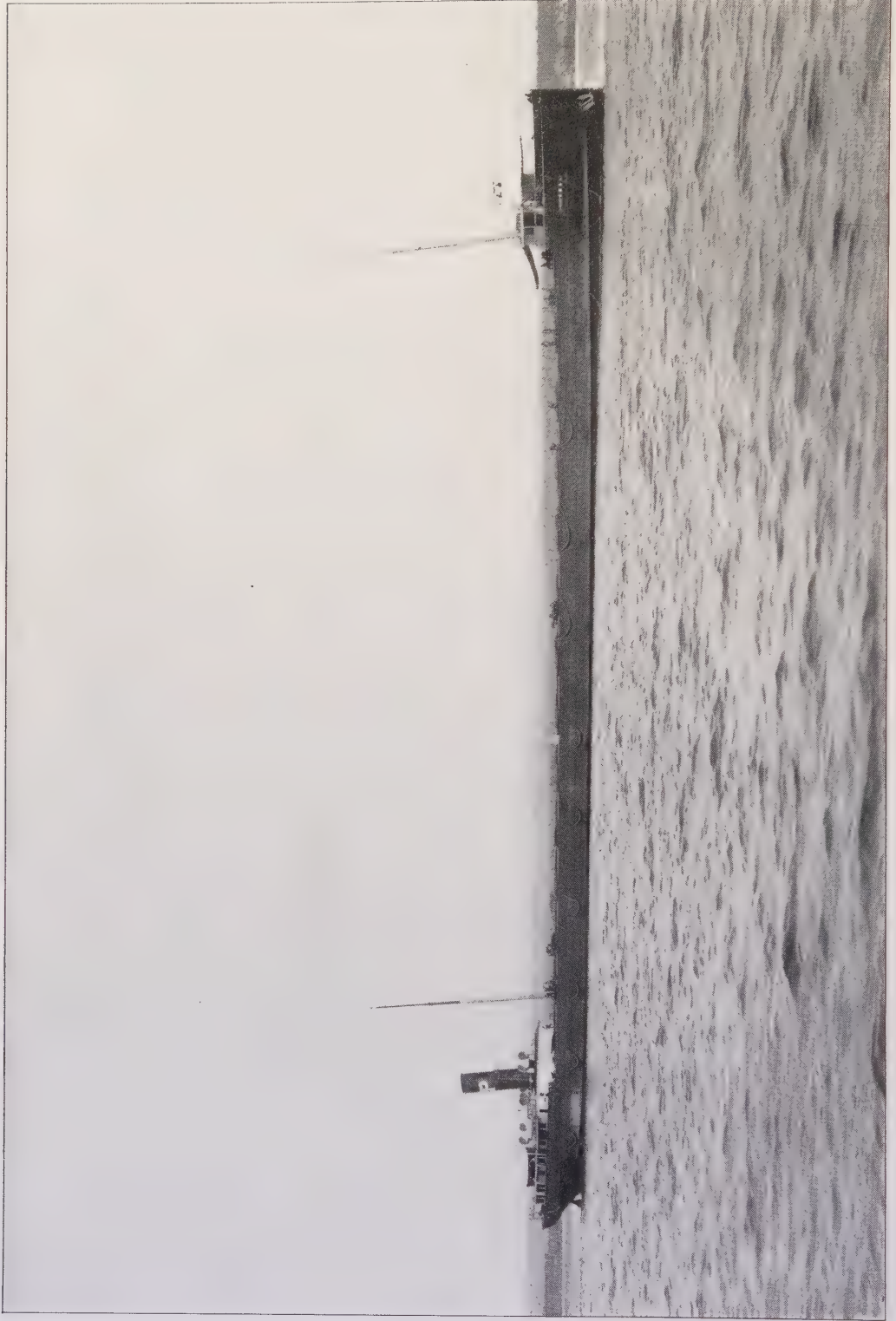
The rate at which water absorbs heat varies slightly as its density decreases, but for rough calculations it can be assumed that the number of degrees Fahrenheit which a pound of water is heated, represents the number of British thermal units it has absorbed.

Suppose, therefore, that a boiler is making steam at 180 pounds gauge pressure and is being fed with water at 60 degrees Fahrenheit. By reference to the steam tables, we find that the boiling point at 180 pounds gauge pressure is about 380 degrees Fahrenheit, and the latent heat equals about 845 heat units. When the water goes into the boiler, therefore, it has first to be heated from 60 degrees to the boiling point, which requires approximately $(380 - 60)$ 320 heat units. This, with the latent heat afterwards added to convert it into steam, makes a total of $(320 + 845)$ 1165 heat units which must be added to each pound of water entering the boiler to make one pound of steam.

If instead of entering the boiler at 60 degrees, the feed water were heated to 200 degrees Fahrenheit, only $(380 - 200)$ 180 heat units would have to be added to bring it to the boiling point instead of 320 as before, and the total heat added per pound of steam would be $(180 + 845)$ 1025 instead of 1165

PERCENTAGE OF FUEL SAVED BY HEATING FEED WATER

Initial Temperature of Water Entering Heater	Heat Units Absorbed in Gener- ating Steam	Temperature of Water Entering Boiler (Steam Pressure 60 Pounds)												
		120°	140°	160°	180°	200°	202°	204°	206°	208°	210°	212°	214°	216°
32°	1175	7.49	9.19	10.89	12.59	14.30	14.47	14.64	14.81	14.98	15.15	15.32	15.49	15.66
40	1167	6.86	8.57	10.28	12.00	13.71	13.88	14.05	14.22	14.40	14.57	14.74	14.91	15.08
50	1157	6.05	7.78	9.51	11.24	12.97	13.14	13.32	13.49	13.66	13.83	14.00	14.18	14.35
60	1147	5.23	6.97	8.72	10.46	12.21	12.38	12.55	12.73	12.90	13.08	13.25	13.43	13.60
70	1137	4.41	6.16	7.91	9.67	11.43	11.61	11.78	11.96	12.14	12.31	12.49	12.66	12.84
80	1127	3.44	5.32	7.10	8.87	10.65	10.82	11.00	11.18	11.36	11.53	11.71	11.89	12.07
90	1117	2.68	4.47	6.26	8.06	9.85	10.03	10.21	10.38	10.56	10.74	10.92	11.10	11.28
100	1107	1.80	3.61	5.42	7.23	9.03	9.21	9.39	9.57	9.75	9.93	10.11	10.29	10.47
110	1097	.91	2.73	4.55	6.38	8.20	8.38	8.56	8.74	8.93	9.11	9.29	9.47	9.66
120	1087	—	1.84	3.67	5.51	7.35	7.54	7.77	7.90	8.09	8.27	8.45	8.64	8.82



S. S. "CORNELL"

OWNERS : PITTSBURG STEAMSHIP CO. BABCOCK & WILCOX BOILERS, 2300 INDICATED HORSE-POWER

heat units. In other words, to each pound of water converted into steam the boiler would now have to add only 88 per cent. of the amount of heat it did before, and 12 per cent. of the coal might be saved, or, providing the same amount of coal was burned on the grates, it would make nearly 14 per cent. more steam than it did with feed water at 60 degrees. The table on page 107 shows the saving that may be expected by heating feed water various amounts.

Another very convincing way of looking at this matter is from the view of engine efficiency. The best engine yet designed, with all the modern improvements of high steam pressure, multiple expansion, condensers, etc., cannot possibly use more than one-fifth of the heat contained in the steam. This is because all the latent heat is necessarily wasted without doing work. How very much more wasteful then must be the pumps, blower engines and other auxiliary machinery on board ship, even if, as is often the case, they exhaust into the condenser.

It is the general impression that auxiliaries will take much less steam if the exhaust is turned into the condenser, thereby reducing the back pressure. As a matter of fact, vacuum is rarely registered on an indicator card taken on auxiliary cylinders unless the exhaust connection is short and without bends, long pipes and many angles vitiating the effect of the condenser.

On the other hand, if the exhaust steam in the auxiliaries can be used for heating the feed water, all the latent heat of this steam, except what is lost by radiation, goes back to the boiler and is saved instead of being thrown away in the condensing water or wasted with the free exhaust. Taking the whole plant into consideration, this makes the auxiliary machinery more efficient than the main engine.

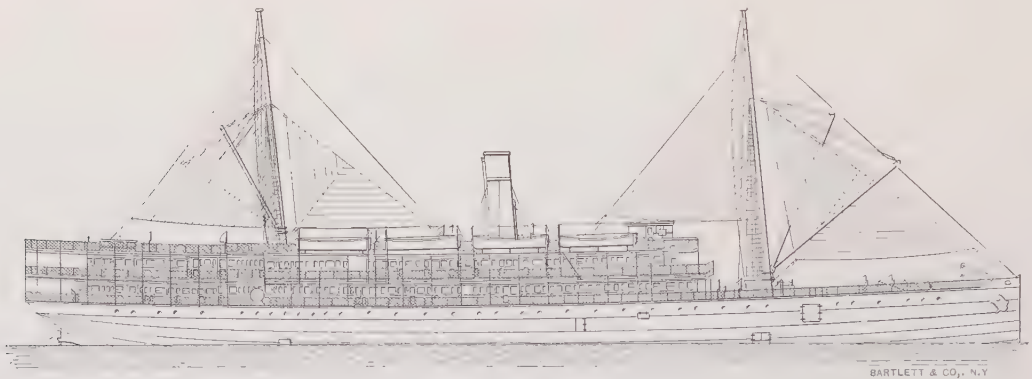
For illustration, take the first of the series of tests of the steamship "Pennsylvania," as found on page 146. The total amount of steam furnished per hour was 20,407 pounds, of which 17,252 pounds were used in the main engine and 3155 in the auxiliaries, *i.e.*, the auxiliaries required 15.46 per cent. of the total steam. Of the 3155 pounds of auxiliary steam, 139 pounds were used by the stoker engines and exhausted into the ash pits, leaving 3016 pounds that exhausted into the heater.

The feed water was taken from the hot well at a temperature of 99.3 degrees Fahrenheit and pumped through a closed feed water heater, where it was heated to 222 degrees Fahrenheit by means of the exhaust steam from the auxiliary machinery. From this heater it passed to the boilers and was converted into steam at a pressure of 242 pounds. The auxiliaries exhausted into the heater at about 3 pounds back pressure.

By referring to the steam tables, it will be found that the 3016 pounds of steam supplied to the auxiliary machinery contained 3,634,280 British thermal units (1205×3016). At 3 pounds back pressure the same amount of steam consumed would contain 3,467,797 British thermal units. The

difference between these amounts—166,483 British thermal units—is all that is available for doing useful work, and as no engine can use all of this without waste, it will be seen that the proportion of heat that is converted into work is very small indeed.

If the exhaust steam from the auxiliary machinery had been turned into the condenser, it is true that not quite so many pounds would have been required each hour, but all the latent heat would have been thrown away in the condensing water, while as a matter of fact, by sending it into the feed water heater, over three-quarters of the entire 3,467,797 British thermal units were saved. This is shown by the heat units absorbed by the feed water which was heated from 99.3 degrees to 222 degrees, a difference of 122.7 degrees Fahrenheit. This multiplied by the number of pounds heated gives $(20,407 \times 122.7)$ 2,503,939 British thermal units as the actual amount of heat taken from the exhaust steam of the auxiliaries each hour and returned to the boiler.



S. S. "SPOKANE"

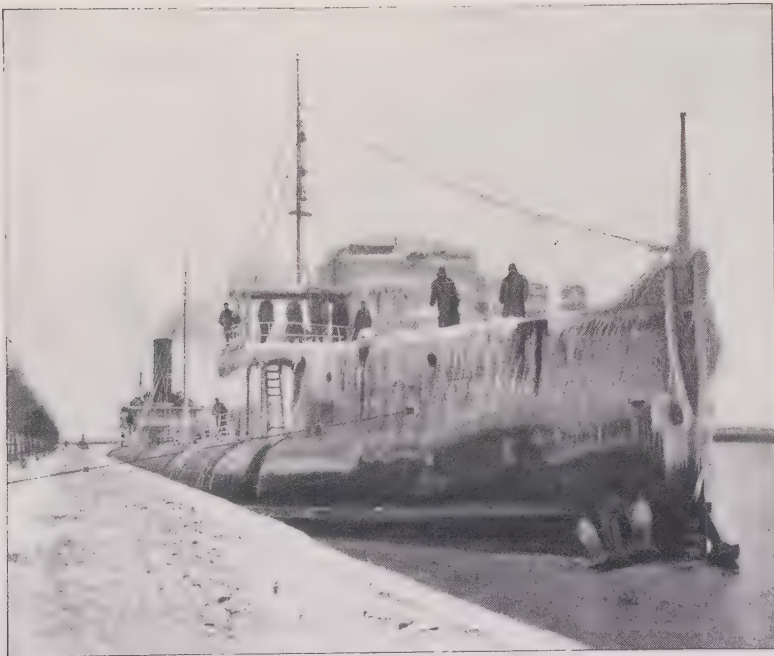
OWNERS: PACIFIC COAST CO. BABCOCK & WILCOX BOILERS, 2500 INDICATED HORSE-POWER

Of the remaining 963,858 British thermal units, part is lost in radiation, condensation in the pipes, etc., and part, amounting to nearly 600,000 British thermal units, is wasted in the drips from the heater, on account of the impossibility of cooling the condensed steam much below 222 degrees Fahrenheit.

It may be noted, further, that each pound of coal burned contained 11,790 British thermal units, of which 75.7 per cent, or 8923 British thermal units were utilized in making steam. If, therefore, 2,503,939 heat units had not been saved by heating the feed water, it would have been necessary to have heated the same by an additional expenditure of 280 pounds of coal per hour, thereby increasing the total coal burned in the plant, per indicated horsepower, to 2.15 pounds instead of 1.92 pounds, as shown by the test.

There is another reason for heating feed water, aside from the obvious saving of heat units, and that is the fact that the boiler steams more economically when using hot feed water than when using cold. This was demonstrated experimentally by Kirkaldy, of England, and the theory advanced by M. Normand seems very plausible, namely, that cold water checks the circulation in the boiler, and in re-establishing this a certain amount of heat disappears in mechanical work, with a consequent loss in evaporation.

Water-tube boilers with their rapid and uniform circulation are not liable to injury by the use of cold feed water, but the above points make it clear that cold water should never be used by the engineer who wishes to obtain the highest economy from his plant.



DECEMBER ON LAKE SUPERIOR



U. S. MONITOR "MANHATTAN"
BARCOCK & WILCOX BOILERS, 1500 INDICATED HORSE-POWER

REBOILERING THE UNITED STATES MONITORS



AT the breaking out of the war with Spain, the United States Government found it necessary to commission every available ship then in ordinary; among these vessels were the old single turret monitors, which were capable of doing good service as harbor defence vessels, provided they could be reboilered at once.

The contract for this work on the "Canonicus," "Mahopac" and "Manhattan," stationed at League Island Navy Yard, Philadelphia, was awarded to The Babcock & Wilcox Company, and the first two vessels were made ready for steam in thirty days and the third in forty-two days after the order to proceed with the work was received.

As the boilers were built in sections, the Government saved much time and expense by passing them into the vessels through the seven-foot armored funnel. Cutting of the decks was thereby entirely avoided.

Originally, each monitor was fitted with two flat-sided Stimer fire-tubular boilers, one on either side of a fore and aft fire room. As soon as one old boiler was cut up and removed, the work of installing the new boilers began, so that construction progressed on one side of the ship while the second boiler was being demolished on the other. The new boilers contained a total of 6000 square feet of heating surface and 200 square feet of grate.

Steam was supplied to a pair of horizontal, crank and lever Ericsson engines, having cylinders 48 inches in diameter and 24 inches stroke. To economize space and obtain a low center of gravity, the cylinders were placed athwartships on the same axial line, and as both were fitted with 16-inch trunk pistons, the effective annular area of the crank end was equivalent to that of a circle 45 inches in diameter. In order, therefore, to equalize the power developed on each side of the piston, it was necessary to allow the steam to follow further on the trunk end than on the head end.

As the engines were constructed before the advent of high pressures, only 50 pounds initial could be carried in the cylinders, although the boilers were constructed for a working pressure of 175 pounds.

It is conceded by the best authorities that the time employed in building and installing the boilers is the quickest on record, and, as to steaming, the Navy Department states: "It is a source of satisfaction that the performance of these vessels with the new boilers exceeded that obtained when the vessels were first built."

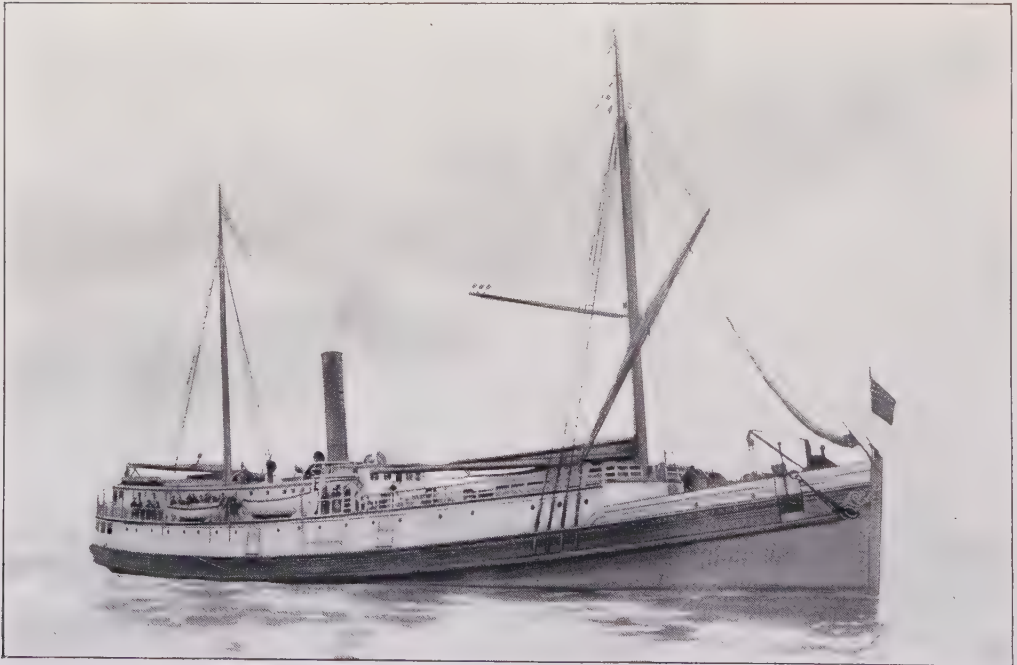
EXAMPLES OF DURABILITY—COST OF REPAIRS



ON the introduction of marine water-tube boilers, the chief, although unwarranted, objection to their use was the "cost of repairs"; those wedded to the Scotch or tank type predicting the necessary renewal of the tubes every two years. Persons interested in the advancement of engineering and anxious to install water-tube boilers have been deterred from so doing by the continued cry, "cost of repairs."

The steamer "Zenith City," equipped with Babcock & Wilcox boilers in the spring of 1895, had, at the completion of the season of 1900, traveled a total of 300,000 miles. The total cost of repairs to each boiler at the end of the fourth year amounted to \$35.00, which sum was expended as much on repairs to boiler fittings as to the boiler proper. At the end of the fifth and sixth seasons no repairs were needed.

The steamer "Charles Nelson" is fitted with these boilers, and the owner states that the steamship "has been in constant and active service at sea upwards of 34 months, and the boilers have given good satisfaction. There has been no expense whatever for repairs, and the boilers are in good condition.



STEAM PACKET "CHARLES NELSON"

OWNER: CHAS NELSON, SAN FRANCISCO, CAL. BABCOCK & WILCOX BOILERS, 850 INDICATED HORSE-POWER

They have shown an excellent economy and furnished plenty of steam, using the various Pacific Coast coals. The 'Nelson' has made good passages to and from Manila, on two occasions equaling the average time made by the United States Army transports."

Concerning the steamer "Dirigo," boilered at the same time as the "Nelson," her owners say that she has been in active service for the same number of months, and the results obtained warranted their installing two similar boilers in the steamship "John S. Kimball," one in the steamer "Archer" and ordering another for a new steamer under construction.

At the expiration of a 12,000-mile voyage from Boston to Cavite, the boilers of the United States gunboat "Marietta" needed only a few grate bars. This run was in addition to the war service of this little vessel, and the memorable trip around the "Horn" in company with the battle ship "Oregon." (See page 37.)

After spending the winter and spring of 1899 on the Atlantic Coast, the cruiser "Chicago" made a trip around Africa, returning to New York *via* South America and stopping at Rio Janeiro. The total distance traveled was 35,000 miles, and, on arrival, she was able to proceed at once to Buenos Ayres, as there was nothing to do to her boilers.

The gunboat "Annapolis" has steamed 60,000 miles, and no repairs have been made.

The steamer "Queen City" completed at the end of the season of 1900 a total of 250,600 miles, and no repairs have ever been made on her boilers.

The steamers "Alex. McDougall" and "Presque Isle" have each carried about 430,000 tons of iron ore, steaming a distance of 130,000 miles. One tube, due to an original imperfection, has been renewed in the boilers of the "McDougall." The "Presque Isle" has needed nothing.

It is a significant fact that vessels equipped with Babcock & Wilcox marine boilers never find it necessary to call in the services of the shop boiler maker.





STEAM PACKET "NOME CITY"

OWNERS: GRAY & MITCHELL, SAN FRANCISCO, CAL. BABCOCK & WILCOX BOILERS, 700 INDICATED HORSE-POWER

CORROSION—CAUSES AND PREVENTIVE MEASURES



S the life of a boiler mainly depends upon the rate of progress of the corrosion of its pressure parts, the prevention or delay of this destructive action is one of the most important duties of the intelligent engineer.

Not only should the subject be studied in its various aspects, but the greatest care and watchfulness are necessary in order to successfully stay the advances of this subtle force.

The principal causes of corrosion of iron and steel boilers, in sea-going vessels, can be classified as follows:

- 1st. Use of sea water.
- 2d. Acidity—the use of animal or vegetable oils in the steam cylinder.
- 3d. Admixture of air with the feed water.
- 4th. Galvanic action.

Each of these causes of corrosion, and means of preventing or remedying them, will be considered separately.

USE OF SEA WATER

Salt water is known to be a solvent of iron or steel, and when boiled under high pressure the magnesium chloride, about 250 grains of which are contained in every gallon, becomes highly corrosive.

ANALYSIS OF SEA WATER

Carbonate of lime		9.79 grains per gallon
Sulphate of lime		114.36 grains per gallon
Sulphate of magnesium		134.86 grains per gallon
Chloride of magnesium		244.46 grains per gallon
Chloride of sodium		1706.00 grains per gallon
Total solids		2209.47 grains per gallon

Under certain conditions, particularly in the process of corrosion, the water becomes acid by the dissociation of magnesium chloride into hydrochloric acid and magnesia; the acid, in contact with iron not protected by scale, forms an iron salt which, at the very moment of formation, is neutralized by the free magnesia in the water, thereby precipitating oxide of iron and reforming magnesium chloride. Thus it is easily seen that free iron is never found in solution in boiler water. The black and red deposits formed in boilers which have had an excess of sea water in them are generally iron oxides. The red is found when there is much air allowed to get into the boiler; the black when little or no air is present.

Just here comes in one of the most astonishing neglects of marine engineering. It is the neglect of *modernizing the condensers* of sea-going ships.

To deliberately install an expensive and well-constructed boiler, and as deliberately permit the use, in connection therewith, of condensers known to be subject to leakage, and constructed so as to make quick and efficient repair extremely difficult, is at least commercially criminal. There is far more room for improvement in design and construction of the condensers than in marine boilers, and the great importance of the former is most obvious when the first cause of corrosion is properly considered.

PREVENTIVE.—To prevent salt feed, the condensers must be tight, and an ample provision made for fresh water “make-up” either by carrying a supply in bulk or by installing an adequate evaporating plant, designed and located so as to operate without priming.

If salt feed does enter the boiler, the quantity must not be increased by “blowing off” water from the boiler, at least not until the saturation has reached $\frac{5}{32}$. A high saturation is preferable to a continuous renewal of salt feed, aside from the heat loss of blowing off.

A light scale will reduce the evaporative efficiency of a boiler, in spite of statements to the contrary, and a heavy scale will induce the burning out of parts exposed to the flames.

REMEDY.—A small amount of salt water is bound to get into the boilers, even under favorable conditions, through priming in the evaporator and slight leakage from the condenser, and it is an excellent plan to constantly use a small quantity of milk of lime to neutralize it. One or two pounds per 1000 indicated horse-power fed per day, in the manner below mentioned, may suffice. The lime used is the ordinary unslaked lime of commerce, and it should be finely powdered and kept in a dry place; for instance, on the up-take gratings.

Milk of lime is a mixture of about one pound of lime to a gallon of water, and should be added at times to the water in the filter box.

THE USE OF LIME.—When starting with new boilers on a voyage for the first time, ten pounds of lime should be put into the boilers for every 1000 horse-power (dissolve in water and put in through man hole); and four to six pounds of lime per day for every 1000 horse-power should be passed through the hot well (as milk of lime) for about six days. At the end of the voyage the boilers should be examined to see if they have a thin coating of lime scale on their interior surface. If this is not the case and the water shows an improper color, the use of the lime should be continued.

The *rationale* of the use of lime is the conversion of magnesium chloride, which is corrosive in effect on iron and steel, into magnesia and chloride of calcium, neither of which is corrosive; and the light scale on the surface also prevents the corrosive elements from coming into contact with the iron.

Further precautionary methods must be employed by the marine engineer in order to conquer corrosion. The boiler water should be tested daily, and if

found to be *acid* or to contain a larger amount than 50 grains of chlorine per gallon, a remedy must be applied.

ACIDITY

This cause of corrosion may arise from salt feed, or from the introduction of animal or vegetable oil with the feed water by reason of using such oils in the steam cylinders, the exhaust steam entraining much of it to the condensers. This oil, containing fatty acids, will decompose and cause pitting wherever the sludgy deposit can find a resting place in the boilers.

PREVENTIVE.—Next in importance to the total exclusion of sea water, is the necessity of keeping oil out of the boiler. Only the highest grade of hydrocarbon oil should ever be used in the steam cylinders, and of this the least possible amount. Also, in lubricating piston rods and valve stems, this same precaution should be observed. For, apart from the evil effects of acidity, the hydrocarbon deposited upon the heating surfaces is most harmful, as a thin film of this deposit forms a complete non-conductor, thereby preventing the heat from passing through into the water, and causing the surfaces to burn, blister and crack.

Where surface condensers are used, the feed water should be purified on its way to the boiler by passing it through a cartridge filter, which must be kept clean. A large amount of impurities are thereby caught, and the condition of the feed water materially improved.

REMEDY.—If the boiler water is *strongly acid*, a solution of carbonate of soda should be added to the feed at the rate of a bucket of soda solution per hour until the water just turns red litmus paper blue, after which daily additions of soda will suffice to keep the water in a safe or alkaline state. Carbonate of soda has also been found effective in cases where scale of sulphate of lime is formed, as it possesses the property of changing the sulphate of lime to sulphate of soda, which is soluble, and, therefore, harmless. Carbonate of lime, which is also formed, may be easily blown or washed out.

To sum up, oil and salt water should never be allowed to enter any kind of a steam generator, and, where surface condensers are used, the feed water should be purified as much as possible before entering the boiler.

Graphite can be used in place of oil as a cylinder lubricant with equally satisfactory results. In fact, graphite is superior to oil when the steam pressure is carried from 200 to 275 pounds, corresponding to a temperature in the neighborhood of 400° F.

Oils containing animal fats produce rapid corrosion and should never be used in the cylinder of a steam engine.

Many steam vessels are running without a particle of oil ever being injected into either their main or auxiliary cylinders, the slushing of the piston rods being found ample for piston lubrication.



U. S. S. "RALEIGH"
EIGHT BABCOCK & WILCOX BOILERS, 8000 INDICATED HORSE-POWER

ADMIXTURE OF AIR WITH FEED WATER

Air has been a well-recognized cause of corrosion for many years, and instances of rapid corrosion have been proved to have been caused by the feed pumps sucking air from the hot well, and the feed being delivered at a level considerably below the water line. The boilers that have been most free from this kind of corrosion are those in which the best means have been adopted to keep out air.

Small bubbles of air expelled from the water on boiling, attach themselves tenaciously to the heating surfaces. The oxygen in this air at once begins war on the iron or steel and forms iron rust; making a thin crust or excrescence which, when washed away by the circulation or dislodged by expansion and contraction, leaves beneath a small hole or pit. Pitting, once started, progresses rapidly, as the indentations form ideal resting places for the bubbles of air, and at the same time present increased surfaces to be attacked.

**Thorpe* states that "nearly all natural waters contain oxygen in solution, and can only be freed therefrom by prolonged boiling in vacuo."

**Spennath* states that water absorbs oxygen as follows :

At 32° Fahrenheit it will absorb 4.9 per cent. of its own bulk

At 50° Fahrenheit it will absorb 3.8 per cent. of its own bulk

At 68° Fahrenheit it will absorb 3.1 per cent. of its own bulk

**Stromeyer* states that under 150 pounds pressure, cold feed water absorbs 3.2 pounds of oxygen per ton.

With independent feed pumps there is less liability for air to get into the boilers than when the pumps are worked off the engines. Air or oxygen is most corrosive in its action, and this is the reason for the boiler feed delivery pipes being fixed either in the steam space or near the water line.

PREVENTIVE.—Where possible, the hot well water should be pumped to a filter tank situated eight to ten feet above the feed pump suction valves. By so doing, a large amount of air rises and is liberated from the surface of the water, and a head of water at the suction valves of the pump is assured.

REMEDY.—Salt water absorbs more air than fresh water. Care should be taken to keep the pump glands tight, and to efficiently entrap free air in the air vessels.

GALVANIC ACTION

Formerly, nearly all corrosion in boilers was attributed to this cause, and zinc slabs were suspended everywhere possible within the water space. The position of zinc relative to that of iron in the scale of electro-positive metals, causes it to be attacked instead of the metal of the boiler when galvanic action takes place.

PREVENTIVE.—To afford protection by the use of zinc, however, there must be positive metallic contact between the zinc and iron. Practically, it is impossible to maintain this contact with the usual methods of installation,

* "Corrosion of Boiler Tubes in U. S. Navy," Lt. Com. Walter F. Worthington, U. S. N., "Journal of the American Society of Naval Engineers," Vol. XII.

and it has been shown that no galvanic current exists after a few hours of steaming, in the arrangements ordinarily employed.

REMEDY.—The use of zinc, however, should not be abandoned on this account, as it appears still a very important element of protection against corrosion due to air in feed water. Its suspension in drums, and points within the boiler near the entrance of the feed, is recommended as of positive benefit, and, indeed, as long as zinc slabs continue to disintegrate and oxidize in a boiler, they deflect to themselves from the iron just that amount of harmful action.

METHOD OF TESTING WATER FOR CORROSIVENESS

The first thing in testing, as is well known, is to see that the color of the water, as shown in the gauge glass, is neither black nor red. The only color



STEAM WHALER "SHELIKOF"

OWNERS: PACIFIC WHALING CO. BABCOCK & WILCOX BOILERS, 450 INDICATED HORSE-POWER

admissible is slightly dirty gray or straw color, unless the water is transparent. So long as the water is red or black, corrosion is going on, and it must immediately be neutralized by freely using lime or soda, and frequently scumming and blowing off, the make-up being provided by the evaporator.

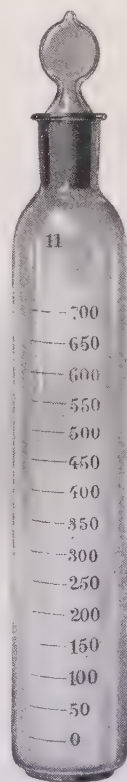
The salinometer is not a very accurate instrument for determining the quantity of sea water in boiler water, but the apparatus here described gives a

convenient and accurate method of ascertaining the exact number of grains of chlorine per gallon in the water tested. It is based on the scheme for the volumetric determination of chlorine devised by Fr. Mohr, an eminent chemist, and requires one graduated bottle, one bottle of silver solution containing 4.738 grams of silver nitrate to 1000 grams of distilled water, and one bottle of chromate indicator, which is a 10 per cent. solution of pure neutral potassium chromate.

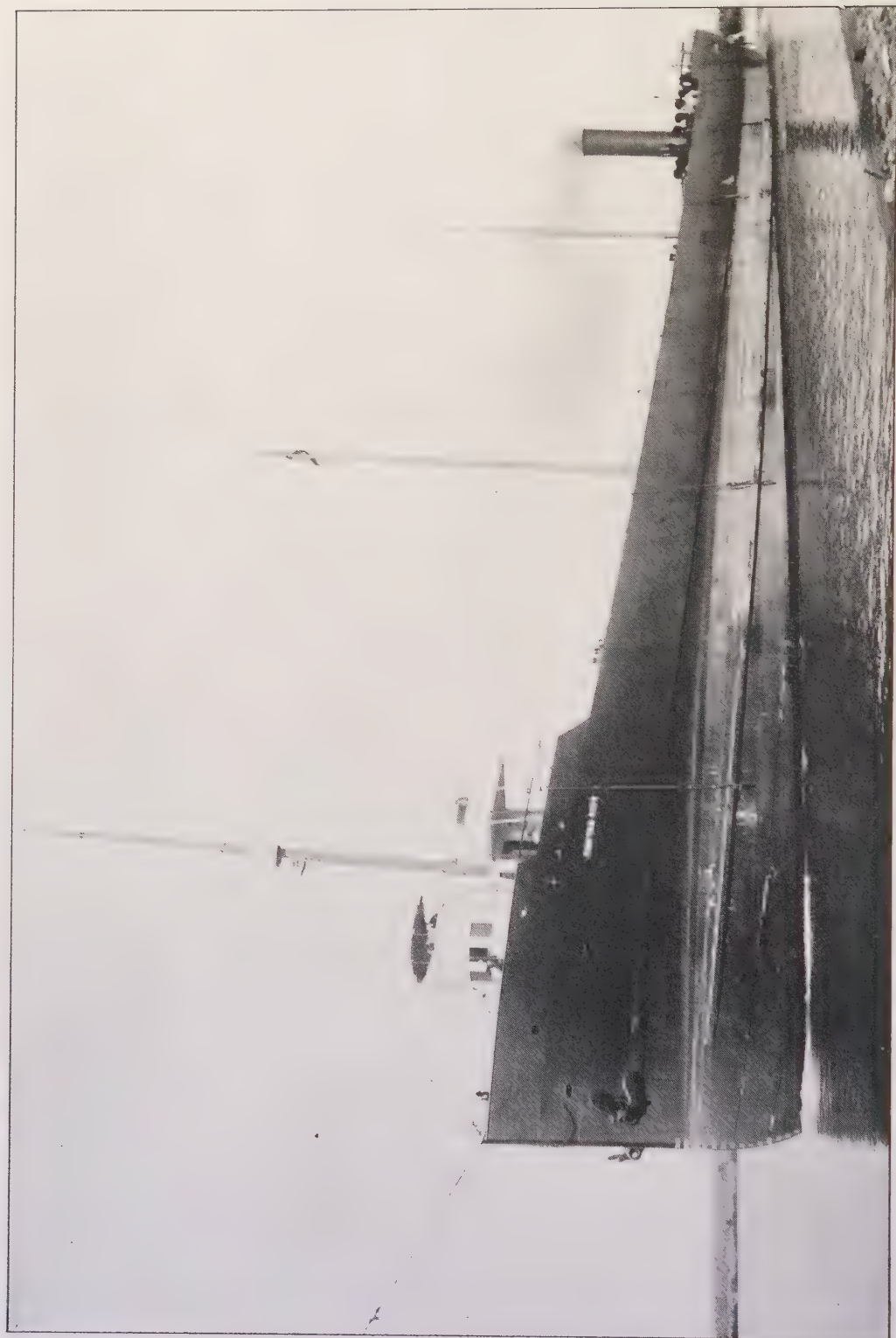
TO MAKE TEST.—Fill the graduated bottle to the zero mark with the water to be tested; add one drop of the chromate indicator; then slowly add the silver solution; keep shaking the bottle. On nearing the full amount of silver solution required, the water will turn red for a moment, and then back to yellow again when shaken. The moment it turns red and *remains red*, stop adding the silver. The reading on the graduated bottle at the level of the liquid will then show the amount of chlorine in grains per gallon. For example, if a permanent red color is shown when the level is midway between 150 and 200, there are 175 grains of chlorine per gallon.

The principle of the process depends upon the fact that if some of this silver solution be dropped into water containing a chloride, a curdy white precipitate of chloride of silver will be formed. If there is also present in the water enough potassium chromate to give a yellow color, the white precipitate will continue to form as before, owing to the silver having a greater affinity for chlorine than for the chromic acid in the chromate. But, at the moment when all the chlorine in the sample has been converted, the silver will attack the yellow potassium chromate, and chromate of silver will be formed, which is red in color. The amount of chlorine present is, therefore, shown by the amount of silver solution required to convert it all to silver chloride, and the determination of the exact point at which the chloride precipitate ceases to form is greatly facilitated by observing when the chromate indicator turns from yellow to red.

It is not necessary to add the silver solution until the color becomes very red, as the delicacy of the reaction would be destroyed, but the change from yellow to yellowish red must be distinct and must not change on shaking. The sample of water to be tested should be neutral, as free acids dissolve the silver chromate. If it should be acid, neutralize by adding sodium carbonate. Slight alkalinity does not interfere with the reaction, but should the sample be very alkaline, it may be neutralized with nitric acid.



GRADUATED BOTTLE



LAKE S. S. "EMPIRE CITY "

OWNERS: ZENITH TRANSIT COMPANY. BABCOCK & WILCOX BOILERS, 2000 INDICATED HORSE-POWER

Should it happen that the color does not change within the limits of the graduations, the sample may be tested by diluting with distilled water. For example, add three parts of distilled water to one part of the sample. If then, on testing the mixture, the color changes at 200, the number of grains per gallon in the original sample will be four times this reading, or 800 grains.

The chlorine should be kept down to the least possible amount—say below 50 grains per gallon—as the nearer the boiler water is to fresh water the safer the boilers are against corrosion.

If the water is so corrosive as to be acid, blue litmus paper, which has not been allowed to become deteriorated through exposure to the atmosphere (keep in a bottle with a glass stopper), will turn slightly red. If a change in color is not apparent at once, it should be allowed to remain in the solution a few minutes and then carefully dried and compared with an unused sample.

Another method is to put into it a few drops of a chemical called methyl-orange. This methyl-orange gives a yellow color so long as the water is alkaline, but if turned pink, it shows that the water is acid, and therefore highly corrosive. This latter test is more sensitive than the litmus paper test, and should be used in preference.

A testing kit containing the graduated bottle and the solutions referred to, also strips of blue and red litmus paper, neatly packed in a padded box, is supplied by The Babcock & Wilcox Company with all boiler installations intended for salt water service.





U. S. ARMORED CRUISER "CALIFORNIA"
BABCOCK & WILCOX BOILERS, 23,000 INDICATED HORSE-POWER

CARE OF BABCOCK & WILCOX MARINE BOILERS



FIRING.—The correct manner of firing boilers depends largely upon the class and quality of the fuel. Coal can be divided roughly into three classes—anthracite, or hard coal; semi-bituminous; and bituminous, or soft coal. When anthracite coal is burned it should be spread evenly over the grate and a fire of uniform thickness maintained, which may be from 3 to 8 inches, depending on the intensity of the draft and size of the fuel. When stoking, half the grate should be covered at a time. In this way, complete combustion is promoted by the fire on the bright half of the grate.

Semi-bituminous coal, that is high in fixed carbon and low in volatile matter, can be fired evenly on the grate or coked just inside the fire door under the reverberatory roof, and then spread back over the incandescent fuel beyond. The coking of the coal at the front of the furnace distills off the volatile gases which burn under the furnace roof before passing among the tubes forming the heating surface.

Bituminous coal, which contains a large percentage of volatile matter and a relatively small amount of fixed carbon, is best burned by stoking light and often and covering about one-quarter of the grate at a time. The fire should be from four to seven inches thick to obtain the best results.

CLEANING.—The efficiency of boilers must be preserved by keeping the heating surfaces clean, both externally and internally. By means of a steam lance and a flexible hose, provided with the boilers, the soot may be almost entirely removed from the tubes, the lance being inserted through the dusting doors in the side casing. In this way the boilers may be cleaned without interfering with the stoking. On arriving in port, the boilers should be swept out, and all deposits of soot removed.

When time in port will permit, the hand hole plates opposite the tubes in the vicinity of the furnaces should be removed, and the interior surfaces examined and washed out; and, if any undue accumulation of scale has taken place, it should be removed by the spoon scrapers or wire brush.

Tubes have been known to blister and crack, and upon removal found to contain only an eggshell of scale thinly deposited over their entire inner surface. Had these tubes been closely examined, before removal, by means of an electric lamp or torch, a small laminated hummock of scale would have been discovered directly over the blister or crack. These small bunches are composed of flakes of scale that have become loosened from other parts of the boiler and carried with the circulation until dammed in some portion of the tube. As these bunches are loose, they may be easily dislodged by

washing out with a hose. Scale burns are most likely to occur when the feed water contains sulphate of lime or when salt water is used for make-up feed.

If the water has a tendency to form a hard scale, such a scale should be removed with the tube scrapers provided. One thirty-second of an inch of scale is the maximum thickness that should be allowed upon the heating surface.



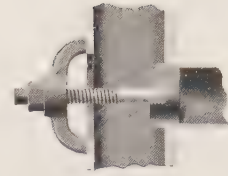
STEAM TUG "EDNA G"

OWNERS: DULUTH & IRON RANGE RAILROAD. BABCOCK & WILCOX BOILERS, 550 INDICATED HORSE-POWER. BREAKING ICE IN DULUTH HARBOR

BLOWING OFF.—Boilers should be blown through the bottom blow valves, at least twice a day, and through the surface blow valve, or scummer, once a watch. Opening these valves wide and immediately closing them is usually sufficient.

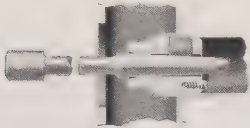
Bottom blows should be used freely after the boilers have been standing with banked fires or quietly steaming. At such times blowing should be more frequently attended to, as the circulation is less active and there is more opportunity for scale-producing deposits to settle on the heating surface.

REPAIRS.—In order to remove a tube, select a narrow ripping chisel from the tool box furnished with all installations, and slit both ends of the tube lengthwise to a depth a short distance beyond the tube seat ; close the expanded portions in, and, after loosening, the tube can be driven out. Care should be taken not to mar the seat in the wrought-steel header into which the tube is expanded.



PLUG EXTRACTOR

The process of removing and renewing tubes is the same as that employed in Scotch boilers, but avoids the necessity of beading over, as the ends are not exposed to the action of the flames, nor the tubes used as stays. To save time in cases of emergency, tubes may be stopped with a conical cast-iron plug supplied for the purpose. As the plug fits the tube, only a few raps with the hammer are necessary to make it tight. The large end of the plug is drilled and tapped, and may be easily withdrawn by the extractor, consisting of wrought steel bridge, bolt and nut, furnished with the boiler. When tubes become defective, they are generally renewed, as the time required is but a trifle longer than that of plugging.



EXPANDER IN POSITION

The expanding of the tubes is performed in the usual manner with expanders and mandrils provided. In replacing any of the short tubes, or nipples, between the headers and mud drum, or headers and steam and water drum, care should be taken that the projecting ends are swelled with the expander. All tubes and nipples should extend beyond their expanded seats one-half an inch.



ORE DOCKS AT TWO HARBORS, MINN.



U S PROTECTED CRUISER "LOUIS"
SIXTEEN BABCOCK & WILCOX BOILERS, 21,000 INDICATED HORSE-POWER

TESTS OF BABCOCK & WILCOX MARINE BOILERS



THE object of testing a steam boiler is to determine the quantity and quality of steam it will supply continuously and regularly, under specified conditions; the amount of fuel required to produce that amount of steam, and sometimes sundry other facts and values. In order to ascertain these things by observation, it is necessary to exercise great care and skill, and employ the most perfect apparatus, or errors will creep in sufficient to vitiate the test and render it of no value, if not actually misleading.

The principal points to be noted in a boiler test are :

1st. The type and dimensions of the boiler, including the area of heating surface, steam and water space, and draft area through or between tubes.

2d. The style of grate, its area, with proportion of air space therein ; height and size of funnel ; area of up-take, etc.

3d. Kind and quality of fuel ; if coal, from what mine, etc. ; percentage of refuse and percentage of moisture in fuel. The latter is a more important item than is generally understood, as in adding directly to the weight, it introduces an error in the final results directly proportioned to the per cent. of the fuel.

4th. Temperature of feed water entering boiler, and temperature of escaping gases. The temperatures of fire room and of external air may be noted, but are usually of slight importance.

5th. Pressure of steam in boiler, draft pressure in furnace, at boiler side of damper, in up-take connection with funnel, and the pressure of the blast, if any, in the ash pit or stoke hold.

6th. Weights of feed water, of fuel and of ashes. Water meters are not reliable as an accurate measure of feed water.

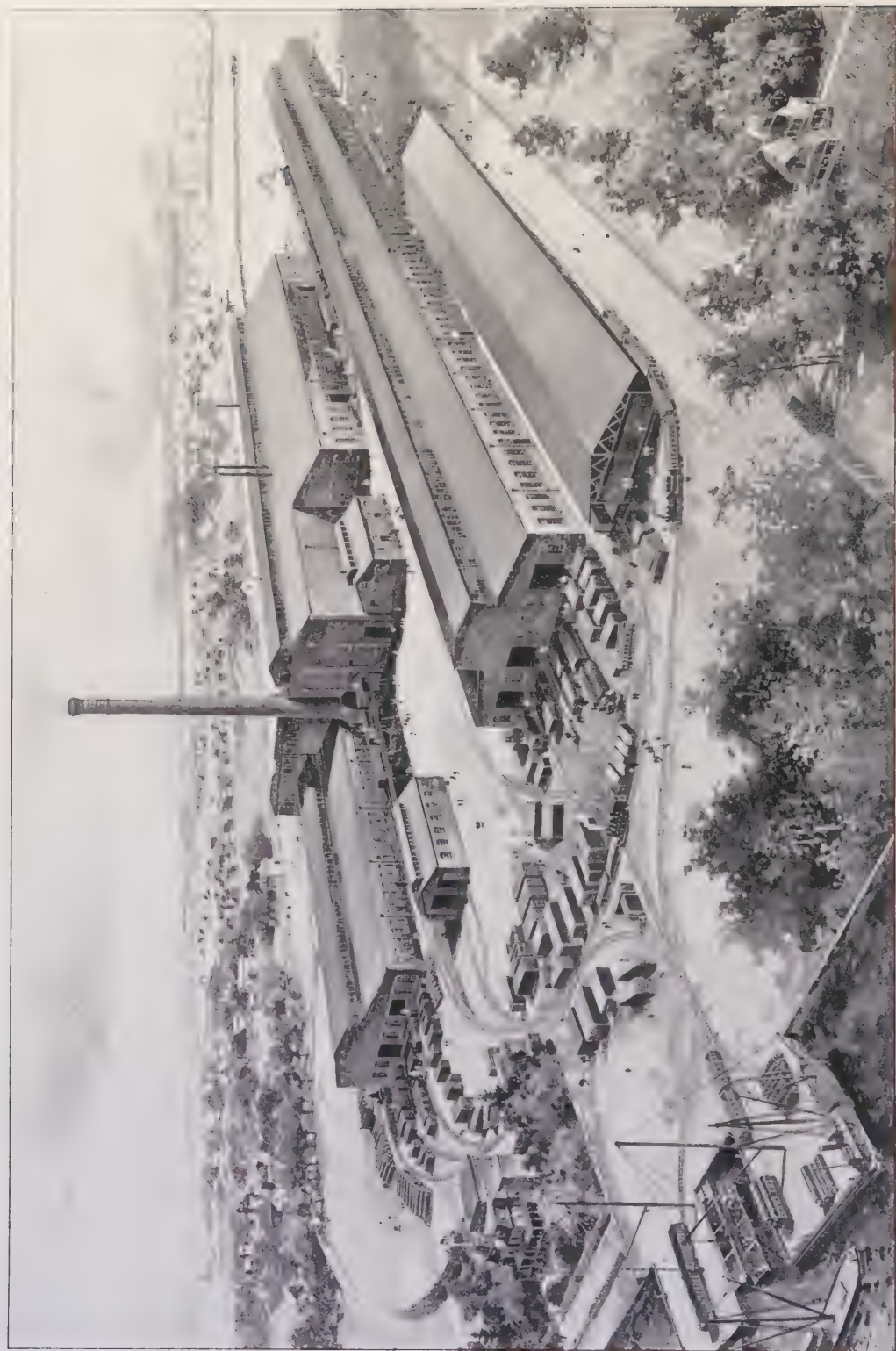
7th. Time of starting and of stopping test, taking care that the conditions are the same at each, as far as possible.

8th. The quality of the steam, whether "wet," "dry" or superheated.

From these data all the results can be figured, giving the economy and capacity of the boiler, and the sufficiency or insufficiency of the conditions, for obtaining the best results.

For purposes of comparison with other tests, the water actually evaporated under the observed conditions per pound of coal and combustible and per square foot of heating surface per hour are reduced to "equivalent evaporation" from and at 212 degrees. (See page 97.)

The standard boiler horse-power is equal to $34\frac{1}{2}$ pounds of water evaporated per hour from and at 212 degrees. The modern marine engine, however, uses only about half a boiler horse-power for each indicated horse-power, and any calculation of the former quantity is of little use for marine purposes.



WORKS OF THE BABCOCK & WILCOX COMPANY, BAYONNE, N. J.

TESTS OF EXPERIMENTAL MARINE BOILER

BUILT BY THE BABCOCK & WILCOX COMPANY AND INSTALLED FOR EXPERIMENTAL PURPOSES AT THEIR WORKS

THE FOLLOWING TESTS WERE MADE ON THIS BOILER UNDER THE CONDITIONS NOTED:

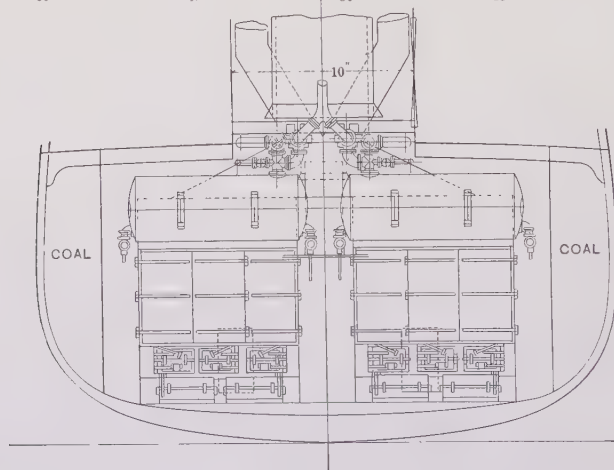
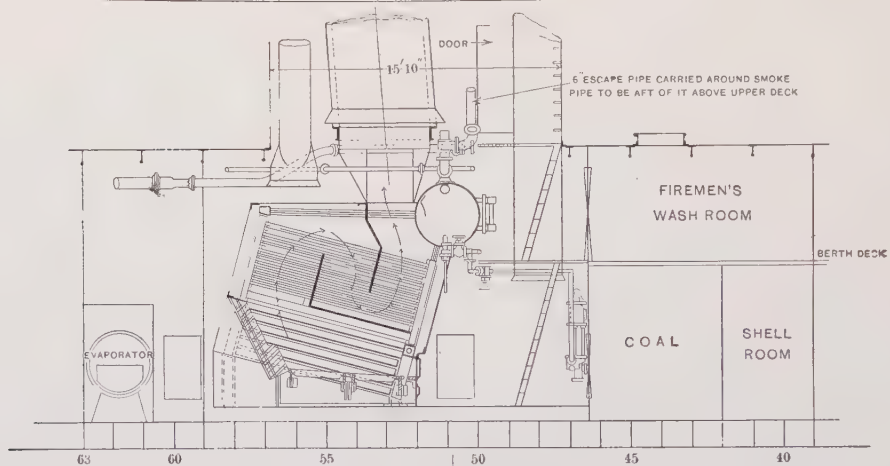
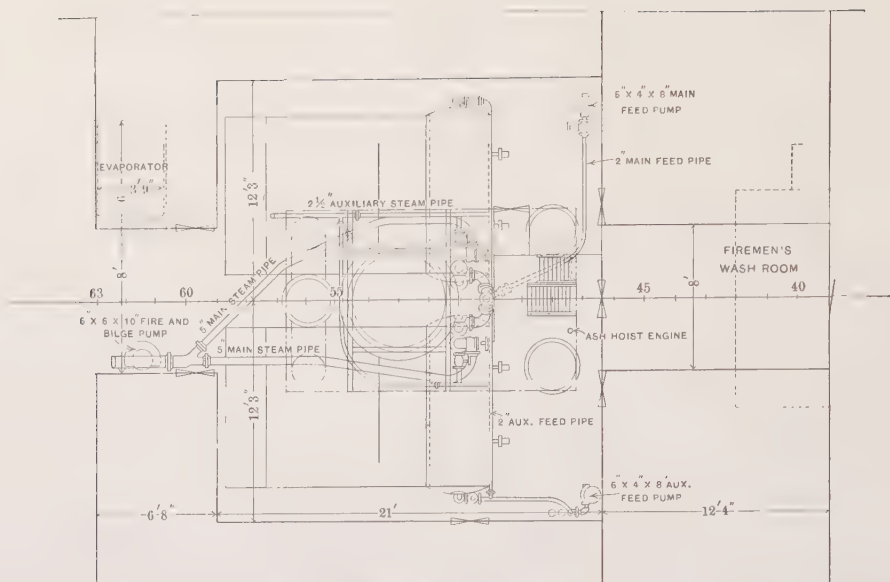
BY THE LATE CHAS. E. EMERY, PH. D., OCTOBER 29TH, 1897: ANTHRACITE EGG COAL; CLOSED STROKE-HOLD BLAST.

BY JAY M. WHITHAM, MEM. AM. SOC. M. E., MAY 7TH, 1895: POCAHONTAS COAL; CLOSED ASH-PIT BLAST.

BY ERNEST H. PEABODY, MEM. AM. SOC. M. E., MARCH 25, 1899: KEYSTONE COAL WITH MECHANICAL STOKER; NATURAL DRAFT.

Engineer conducting test	C. E. Emery	J. M. Whitham	E. H. Peabody
Date of test	Oct. 29th, 1897	May 7th, 1895	Mar. 25th, 1899
Duration of test, hours	7½	24	6.0
Heating surface : 1337 in boiler			
215 in heater, sq. ft.	1552	1552	1552
Grate surface, sq. ft.	33.25	38.5	45.7
Ratio of heating surface to grate surface	46.67	40.03	33.96
Kind of fuel	Lackawanna egg, Woodward Mine	Pocahontas run of mine	Keystone run of mine
Steam pressure by gauge, average, lbs.	200	154	113
Force of draft in inches of water, closed stoke hold	+0.99	....	} Natural draft
Force of draft in inches of water, closed ash pit	....	+0.98	
Force of draft in inches of water at base of funnel, average	-0.49	-0.54	-0.35
Force of draft in inches of water in furnace, average	+0.14	-0.04	-0.15
Temperature of feed water, average deg. Fahr.	108.8	66.0	61.3
Temperature of water from heater, average deg. Fahr.	230.8	147.9	151.0
Temperature in upper part of closed fire room, average deg. Fahr.	95.2	....	....
Temperature of flue gases	Antimony did not melt*	By Pyrometer	Bismuth melted*
Per cent. of refuse in coal	7.98	607° F.	Lead did not
Quality of steam (by Barrus calorimeter with calibration)	Dry	5.38	12.6
Average water per hour evaporated into dry steam under actual conditions, lbs.	9619	Dry	Dry
Water evaporated per pound of coal, from and at 212°, lbs.	8.36	12.493	5270
Water evaporated per pound of combustible, from and at 212°, lbs.	9.08	8.29	10.11
Coal per sq. ft. of grate per hour, lbs.	40.29	8.76	11.65
Water evaporated per sq. ft. of heating surface per hour, under actual conditions, lbs.	6.20	46.9	13.7
Water evaporated per sq. ft. of heating surface per hour, from and at 212°, lbs.	7.21	8.05	3.39
Water evaporated per sq. ft. of grate per hour, from and at 212°, lbs.	336.72	9.67	4.07
		389.7	138.2

* Antimony melts at 840° F.; lead at 625° F., and bismuth at 510° F.



ARRANGEMENT OF BOILERS OF U. S. S. "ALERT"

TESTS OF A BABCOCK & WILCOX BOILER BUILT FOR THE U. S. S. "ALERT" *

TESTS CONDUCTED BY A BOARD OF NAVAL ENGINEER OFFICERS CONSISTING OF
LT.-COM. GEO. W. McELROY, LT. W. W. WHITE AND LT. EMIL THEISS

The "Alert" will have two boilers placed side by side in the ship, with a passage-way between them, facing an athwartship fire room.

The dimensions, over all, of the boilers are: Length at bottom of ash pit, 11 feet 1 inch; distance from boiler front to perpendicular from center of drum, 19 $\frac{1}{8}$ inches; length at top from back end to center of drum, 10 feet 5 $\frac{3}{8}$ inches; width of boiler, 8 feet 9 inches; height from bottom of ash pit to center of drum, 10 feet 8 $\frac{1}{2}$ inches.

Heating surface, outside of tubes, square feet	2012
Heating surface in boxes, square feet	93
Heating surface in drum, square feet	20
Total heating surface	2125

Grate surface (length of grate, 6 feet 4 inches) square feet	48
Ratio heating surface to grate surface	44 : 1

Air heater :

Number of tubes (each 3 inches diameter and 6 feet long)	102
Heating surface in tubes, square feet	481
Area through tubes, square feet	4.3
Least area between tubes for up-take gases, square feet	7.25

Smoke pipe :

Diameter, feet and inches	3-6
Height, feet	48

Boiler :

Weight of boiler, dry-weighed on car, complete, pounds	46488
Total weight of boiler and water, pounds	54638

The weight of water necessary to fill this boiler to 5 inches in gauge glass (which is at the middle of the drum), is 8833 pounds, or 8150 pounds for same level at temperature due to boiling water under 225 pounds pressure.

DESCRIPTION OF TESTS

Four separate tests were made, on April 11, 12, 13 and 14.

The first was with cold air, closed ash-pit draft, and a steam jet in the smoke pipe. This test was intended to demonstrate the performance, under the conditions stated, of the boiler with the maximum consumption of coal that it is expected to reach in naval practice.

The second test was with open ash pit, a steam jet being used in the chimney to produce a partial vacuum about equivalent to that due to the height of smoke pipe as on the ship, viz., about 0.45 inch of water.

The third was with heated air, closed ash-pit draft, and a steam jet in the chimney. The blower drew the air through the heater tubes and discharged it into

* Extracts from the annual report for 1899 of Admiral Geo. W. Melville, Engineer-in-chief of the United States Navy.

the back of the ash pit. The conditions as to draft, method of firing, and temperature of feed were as nearly as possible the same as in test No. 1, the object being to establish the effect due to the heating of the air.

In all the three preceding tests Cumberland coal was used. During the first and the greater part of the second test it was George's Creek coal. During the latter part of the second test, and throughout the third test, another shipment of coal, also Cumberland, was used. This last coal contained less slack and less surface moisture than the first, but all was of excellent and presumably of very similar quality.

The fourth test was with cold air, closed ash-pit draft, and a steam jet in the chimney, and was undertaken to show the efficiency of the boiler using hard coal under moderately strong forced draft.

Attention is especially directed to the comparative results of tests made April 13 in presence of the Board, and on April 19 by the firm. These two tests were made under nearly identical conditions as to draft, temperature of feed, and method of firing, except that during the test of April 13 the air heater was in use, while on April 19 it was not, and would seem to show that with the ratio of grate to heating surface, and the circulation of gases secured in the boiler under test, the up-take gases escape at so moderate a temperature that the air heater is of little value. The data of the tests, bearing on this point, are given in the table on the following page.

The results of the parallel tests, with and without air heaters in use, made by the Board on April 11 and on April 13, are somewhat vitiated by the fact that the coal used was not from the same shipment in the two cases; and, while from the same coal region, and presumably of very similar heating value, the first lot contained about 4.09 per cent. of surface moisture, and was composed of nearly 75 per cent. slack, while the second lot contained 2.77 per cent. of surface moisture, and contained much less slack—about 50 per cent.

The following experiment, made April 22, in the presence of Lieut. (then Chief Engineer) G. W. McElroy, United States Navy, gives the time required for raising steam under the conditions stated.

Fires were started with wood and oily waste in front. About one-half shovelful of kerosene was thrown on just after lighting the fires. Soft coal was used toward the end. The boiler was at atmospheric temperature when fires were lighted, the water at the temperature of 54° F. Its height in the gauge glass on starting fires was 1 $\frac{1}{4}$ inches. Almost immediately after the fires were started the circulation of the water began, as evidenced by the temperature of the different parts of the boiler.

RECORD OF RAISING STEAM

Time	
11.31	Lighted fire. 1 $\frac{1}{4}$ inches water in boiler gauge glass. Natural draft
11.42	Began to make steam. No pressure on steam gauge
11.44 $\frac{1}{2}$	5 pounds pressure on steam gauge
11.45	10 pounds pressure on steam gauge
11.46 $\frac{1}{4}$	20 pounds pressure on steam gauge
11.47	25 pounds pressure on steam gauge
11.48 $\frac{3}{4}$	40 pounds pressure on steam gauge
11.49 $\frac{3}{4}$	50 pounds pressure on steam gauge

TABLE OF RESULTS OF TESTS OF A BABCOCK & WILCOX MARINE BOILER, BUILT FOR THE U. S. S. "ALERT,"
AT ELIZABETHPORT, N. J.

Ratio of Heating Surface to Grate Surface, 44:1									
Heating Surface, 2125 square feet									
Number of test	April 6	April 8	April 11	April 12	April 13	April 14	April 19	April 20	April 21
Date	April 6	April 8	April 11	April 12	April 13	April 14	April 19	April 20	April 21
Kind of coal	Honey Brook Chestnut	1st lot Cumberland	2nd lot Cumberland	Lackawanna egg	3rd lot Cumberland	Cardiff	Cardiff	Cardiff	Cardiff
Kind of firing	Thin. 1 door each firing	Spreading thin and raking. 3 doors each firing	Covering two-thirds back	Spreading thin, slightly raking doors and back	Covering two-thirds back	Thin. 1 door each firing	Covering two-thirds back. Duplicate of April 13	Spreading thin. Making duplicate of April 8	Spreading thin
Moisture in coal, per cent.	0	5.25	4.09	3.91	2.77	0	2.5	2.0	1.0
Refuse in dry coal, per cent.	....	9.56	7.39	9.00	10.50	12.33	10.41	11.60	7.88
Boiler pressure, lbs.	117	203	219.3	129	218.6	218.2	205.1	203.8	203.7
Temperature of feed, deg.	100	157.2	93.4	110.1	91	110.5	93	152.6	160.5
Factor of evaporation	1.1597	1.1131	1.1814	1.1514	1.1839	1.1836	1.1813	1.1118	1.1017
Drafts { Stack, in.	— .50	— .61	— .43	— .43	— .40	— .61	— .41	— .23	— .26
Blast in ash pit, in.	— .35	— .31	— .21	— .21	— .26	— .07	— .22	— .15	— .14
Hot blast { Temperature entering heater, deg.	....	....	....	....	....	....	....	....	....
{ Temperature entering ash pit, deg.	....	....	....	....	....	....	....	....	....
{ By pyrometer, deg.	387	498	595	446	562	521	578	414	444
{ By thermometer, deg.	....	....	....	44	572	518	554	406	423
Temperature flue gases { Metal melted, deg.	....	....	....	Tin and Bismuth	Lead	Bismuth	Lead	Tin	Tin
Flue gas analyses { CO ₂ , per cent.	....	....	11.9	10.7	10.9	11.1	10.3	10.2	10.8
{ O ₂ , per cent.	....	....	7.8	7.7	8.2	8.7	8.1	8.8	8.1
{ CO, per cent.	....	....	0.5	.2	.06	0.0	0.4	0.1	0.1
Moisture in steam—decimals of 1 per cent.	....	....	.10	.04	.10	.05	0.0	0.0	0.0
Duration of test, hrs.	2944.8	7059.0	10419.2	8937.0	10250.0	7604.0	9791.7	4178.0	5862.6
Total water actual conditions, lbs.	24151	79374	123692	103133	121350	88480	115670	46710	69987
Total water from and at 212 deg., lbs.	7482	10474	17305	8868	17083	12673	16320	7203	10317
Water per hour { Actual conditions, lbs.	8329	11131	20515	10111	20225	14747	19278	8653	11343
Water per sq. ft. of { Actual conditions, lbs.	149.6	208.3	351.8	184.7	355.9	264	340	150.1	212.8
Water per sq. ft. of heating { Actual conditions, lbs.	173.5	231.9	427.4	212.7	421.3	307.2	401.0	107.8	183.1
surface per hour { From and at 212 deg., lbs.	3.38	....	....	....	....	....	....	....	....
Total coal, lbs.	3400	7550	13693	10016	951	8300	11800	4360	5800
Total dry coal, lbs.	3400	7154	13073	9624	12003	8300	11505	4273	5742
Dry coal per hour, lbs.	829.3	1014.7	2178.8	952.9	2040.5	1383.3	1917.5	736.7	1060.3
Dry coal per sq. ft. of grate per hour, lbs.	17.27	21.14	45.39	19.35	48.8	28.82	39.33	15.35	22.09
Water per lb. of coal { Actual conditions, lbs.	8.66	9.85	16.77	10.11	8.50	9.16	9.51	9.78	16.16
Water per lb. of combustible from and at 212 deg., lbs.	10.05	10.97	19.77	10.72	10.50	10.66	10.05	10.93	10.21
Heat value of fuel—B. T. U. per lb. of dry coal	....	14670	14670	11778	1124	12.16	11.22	12.30	11.89
Efficiency of boiler—dry coal basis	....	72.3	61.95	70.95	67.30	74.6	67.25	73.15	74.9

NOTE: The tests of April 11th to 14th, inclusive, were made by the Board of Naval Engineers detailed by Admiral Melville, and the tests bear the numbers referred to in his report. The remaining tests were made for The Babcock & Wilcox Company by E. H. Peabody, Mem. Am. Soc. M. E.

RECORD OF RAISING STEAM—*Continued*

Time	
11.51	65 pounds pressure on steam gauge. 4½ inches water in boiler gauge glass. Put on blower
11.51¾	75 pounds pressure on steam gauge
11.52¾	100 pounds pressure on steam gauge
11.53	105 pounds pressure on steam gauge
11.53¾	125 pounds pressure on steam gauge
11.54¾	150 pounds pressure on steam gauge
11.55¾	175 pounds pressure on steam gauge
11.56¾	200 pounds pressure on steam gauge
11.57¾	225 pounds pressure on steam gauge. 5½ inches water in boiler gauge glass. Safety valve blowing. Stopped blower

The table contains the calculated results and final averages. The evaporation has been figured out on the basis of dry coal and combustible consumed, and water evaporated into steam of the calculated quality.

On the completion of the tests the boiler was thoroughly examined inside and outside.

The grate bars and bearers had not suffered the least injury, nor did the fire-brick back, or the fire-brick baffles supported upon the row of 4-inch tubes over the furnace, show signs of distress.

The entire outer casing plates opposite the tubes were removed on one side and the magnesia and fire-brick lining taken down, exposing the tubes and making possible an examination of the sectional vertical baffles. These, as well as the inclined deflector in the space above the tubes, were found in perfect condition. The edges were sharp and no warping was noticeable. The 4-inch tubes immediately above the furnace were perfectly straight.

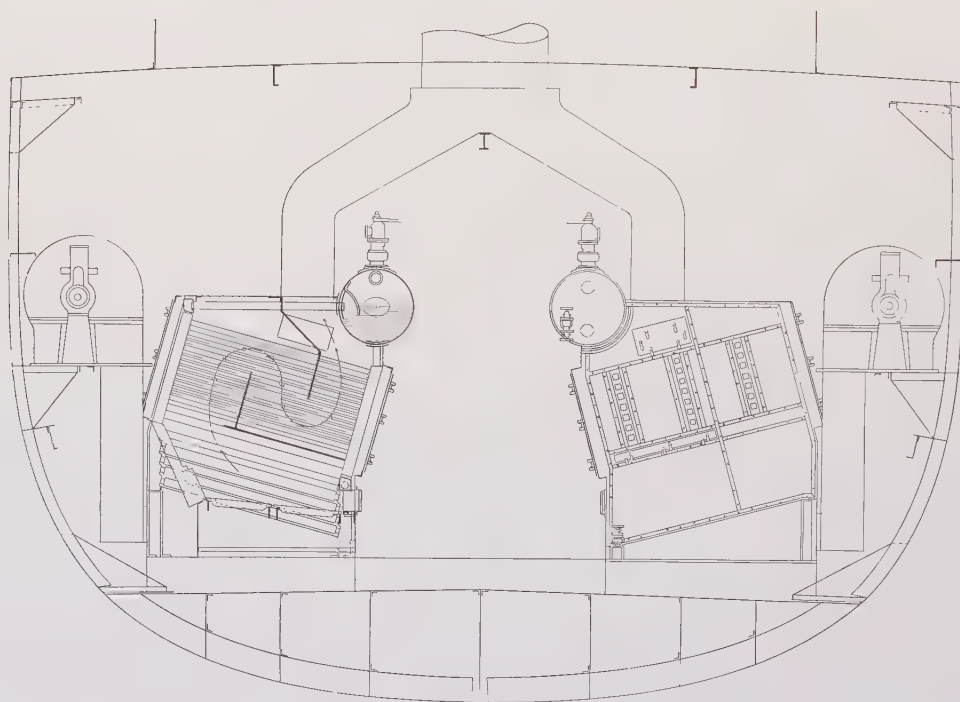
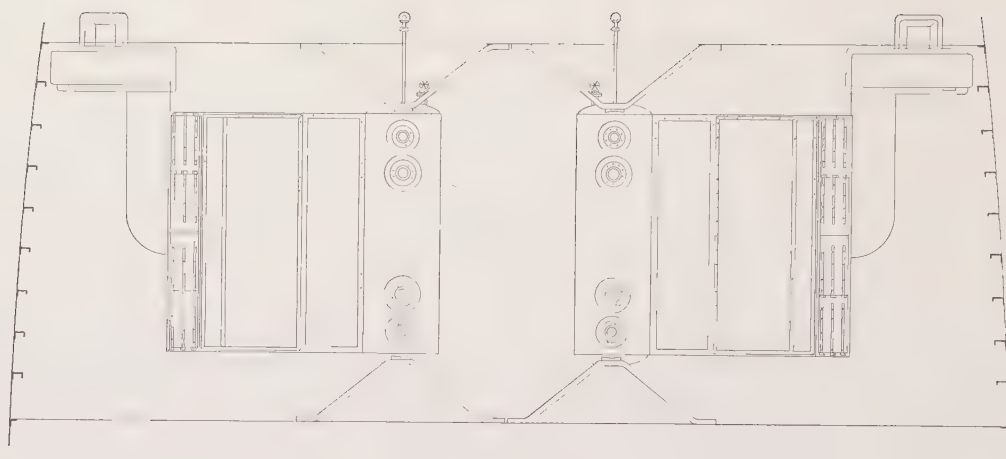
Generally speaking, the tests conducted must be regarded as most satisfactory. The boiler did its work under natural and under forced draft with good economy and without distress. The comparatively low temperature of the up-take gases during all the tests both with and without the air heater in use seems to indicate that the air heater is not a necessity in combination with a boiler of the design in question, and can not be considered a desirable adjunct except possibly when working at very high rates of combustion.



RESULTS OF SEA TRIALS FROM ENGINEERS' REPORTS

SHIPS FITTED WITH BABCOCK & WILCOX BOILERS

	"Turret Chief"	"Turret Court"	"Hero"	"Cameo"		"Turret Cape"		"Orlando"	
Date of trial	24-2-97	23-3-97	5-11-95	7-1-96	9-3-96	24-4-96	28-8-96	17-3-98	28-1-98
Ship length, feet	253	253	253	217	245	245	253	253	274
Ship breadth, feet	44	44	44	30	31	31	44	44	32
Ship depth, feet	21.75	21.75	21.75	13.6	17.35	17.35	21.75	21.75	19
Gross tonnage	1900	1900	1900	775	1244	1244	1900	1900	1197
Cylinders and stroke, inches {	20-34-57	20-34-57	20-34-57	18½-31-53	18½-31-53	18½-31-53	21½-36-59	21½-36-59	18½-31-53
	39	39	39	33	33	33	39	39	36
Kind of coal used	Poor Welsh	Newcastle	Welsh	Hard Yorkshire	Hard Yorkshire	South Yorkshire	Welsh	Newcastle	South Yorkshire
Tons per day	17	17.1	18	20	21	21	13.3	14.2	21.8
Indicated horse-power	952	844	1109	1100	1060	1261	811	805	1250
Coal per indicated horse-power	1.6	1.89	1.52	1.7	1.8	1.6	1.53	1.65	1.67
Heating surface	4500	4500	4500	4400	4400	4400	4584	4584	4500
Grate surface	98	86	80	72	90	88	110	110	94
Ratio of H. S. to G. S.	46:1	52:1	56:1	61:1	48:1	50:1	41:1	41:1	48:1
Baffle opening to G. S.	1.6	1.1	1.8	1.8	1.8	1.1	1.6	1.8	1.1
Funnel temperature, degrees	703	550	700	580	635	530	550	500	570
Speed, knots per hour	10.1	9.8	11.2	12.5	12.12	12.45	9.5	9.75	11.7
Revolutions	72.5	55	78	73	96	84	56	52	90
Steam pressure	200	200	200	200	200	200	200	200	220

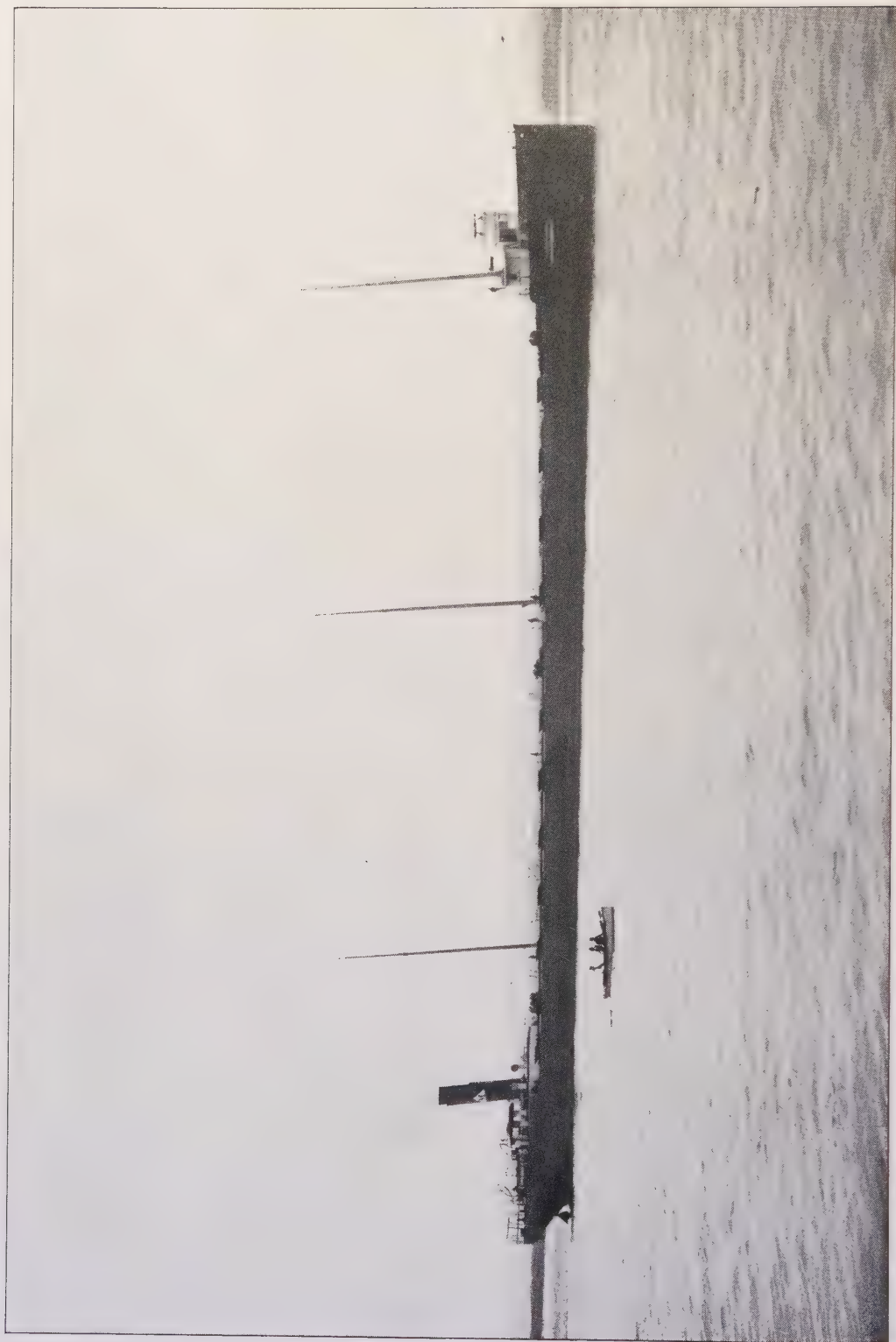


ARRANGEMENT OF BABCOCK & WILCOX BOILERS IN LARGE
LAKE CARGO STEAMERS

TESTS OF MACHINERY OF 6500-TON LAKE STEAMERS

(Equipped with Babcock & Wilcox Marine Boilers)

Name of vessel	Date of Test	Duration of Test Hours	Steam Pressure Lbs. per Sq. Inch			Vacuum Inches	Revs. per Minute	Temp. of Water		Coal per Hour		Water per Hour for All Purposes		Water per Main Eng. Only	Actual Condi- tions	Water per Lb. of Coal	Total I. H. P.	I. H. P. per Sq. Ft. of Vessels	Name of Engineer Conducting Test	Remarks		
			At Boilers	In 1st L. P.	In 2d L. P.			In L. P.	In Hot Well	Feed En- gines	Total	Per Sq. Ft. of Grate	I. H. P.								Total	I. H. P.	From and at 212
Zenith City	Oct. 20, '95	24	190.3	57.7	..	20.12	22.6	75.5	116.5	..	3475.8	25.94	2.26	24503	15.91	..	7.05	8.14	1540.2	11.49	13.18	J. H. Perry, (Chief Eng.)
Zenith City	to	9.56	195.2	59.9	..	20.9	22.85	85.9	117.8	..	3502.6	26.59	2.22	24963	15.84	..	7.01	8.09	1607.3	11.99	13.18	U. S. N. and B. C. Bryan, P. A. Eng., U. S. N.
Zenith City	Oct. 25, '95	3	191.7	55.7	..	20.5	22.5	91.5	117.3	..	3556.7	26.54	2.19	25078	15.42	..	7.05	8.03	1626.5	12.13	13.18	U. S. N.
Queen City	July 8, '96	31	210	42	..	4.8	23	72.7	..	..	2056	20	..	..	..	..	..	..	..	..	..	W. D. Hoxie
Crescent City	July 15, '97	10	244	..	..	..	24	76.7	133	243	2420	20.16	..	23456	..	..	9.69	9.93	..	..	..	W. D. Hoxie
Crescent City	Sept. 13, '97	12	241.9	101.9	28	4.4	22.36	76.57	130	181.2	2500	20.83	1.86	24304	18.14	..	9.72	10.02	1389	11.15	13	J. F. Hayes
Superior City	Aug. 3, '98	12	244.4	99.3	34.8	1.59	26	75.62	117.2	185.7	2270	15.33	1.76	..	..	..	..	..	1284.5	9.88	11.4	J. F. Hayes
Empire City	Aug. 10, '98	12	245	101.2	31.3	2.08	24	75.82	120	188.9	2133.3	16.28	1.64	..	..	..	..	..	1304.7	10.83	11.5	J. F. Hayes
Queen City	Sept. 15, '98	12	219.3	55.8	..	7.92	23	77.16	132	..	2120	17.66	1.71	..	..	..	..	..	1237	11.45	13	J. F. Hayes
Queen City	June 15, '99	4	218.3	57.3	..	8.9	25.9	78.92	116	180	2241.2	20.75	1.74	18900	14.7	13.63	..	1286.1	11.99	12.8	E. H. Peabody	
Queen City	June 15, '99	2	218.2	58	..	9.0	23.95	77.47	116	180	2246.4	20.73	1.78	18860	14.99	13.65	..	1288.1	11.64	11.2	E. H. Peabody	
Queen City	June 17, '99	6	220.1	57.5	..	7.6	23.9	74.87	116.7	171	2001.3	18.53	1.75	16425	14.36	13.4	8.21	9.04	1144.1	10.59	11.33	E. H. Peabody
Lafayette	Dec. 2, 1900	6	235	..	..	..	22.5	83.1	134	180	2852	21.9	1.60	25178	14.09	..	8.83	9.65	1785.9	13.74	..	F. B. Smith



LAKE S. S. "PENNSYLVANIA"

OWNERS: MINNESOTA STEAMSHIP CO. BABCOCK & WILCOX BOILERS, 2000 INDICATED HORSE POWER

TESTS OF MACHINERY OF S. S. "PENNSYLVANIA"

At the request of Mr. A. B. Wolvin, of Duluth, the Babcock & Wilcox Company installed its testing apparatus on board the Minnesota Steamship Company's new steamer "Pennsylvania"* for the purpose of making a series of tests of that steamer's machinery.

Advantage was also taken of this opportunity by the Navy Department to secure exact data regarding the economy of the boilers, the steam consumption of the main engine and auxiliary machinery, and the working of the mechanical stoker with which the ship was fitted. Accordingly, Lieutenants B. C. Bryan and W. W. White were detailed by the Bureau of Steam Engineering to make a trip with the ship and conduct the trials.

The results obtained were published in Vol. XI., Part 3, of the "Journal of the American Society of Naval Engineers," from which we quote the following :

"The main propelling engine is of the vertical, direct-acting, inverted, jet-condensing, quadruple-expansion type, designed for a maximum horse-power of about 2000.

Number of cylinders, unjacketed	4								
Diameter of cylinders, in inches	<table> <tr> <td>{ High-pressure</td><td>15$\frac{3}{4}$</td></tr> <tr> <td>{ First intermediate-pressure</td><td>23$\frac{3}{4}$</td></tr> <tr> <td>{ Second intermediate-pressure</td><td>36$\frac{1}{2}$</td></tr> <tr> <td>{ Low-pressure</td><td>56</td></tr> </table>	{ High-pressure	15 $\frac{3}{4}$	{ First intermediate-pressure	23 $\frac{3}{4}$	{ Second intermediate-pressure	36 $\frac{1}{2}$	{ Low-pressure	56
{ High-pressure	15 $\frac{3}{4}$								
{ First intermediate-pressure	23 $\frac{3}{4}$								
{ Second intermediate-pressure	36 $\frac{1}{2}$								
{ Low-pressure	56								
Stroke, inches	40								
Diameter of piston rods, inches	4 $\frac{3}{4}$								

"Steam is supplied by two boilers of the Babcock & Wilcox water-tube marine type, built for a pressure of 250 pounds. Each boiler is 9 feet 3 inches long, 12 feet 6 inches wide, and 16 feet 8 inches high, containing 3000 square feet of heating surface and suitable for 65 square feet of grate surface.

Weight of boilers, dry, pounds	145,860
Weight of water contained, pounds	33,492
Total weight of boilers and water, pounds	179,352

"All steam-generating tubes are 2 inches in diameter, No. 10 B. W. G. in thickness and 7 feet 3 inches long, the connecting tubes being 4 inches in diameter and No. 6 B. W. G. in thickness. The sides of the boilers are formed by 2-inch tubes inclined the same as the generating tubes, but placed one above the other and expanded into straight manifolds or corner boxes.

"Three mechanical underfed stokers are fitted to each boiler. These were installed by the American Stoker Company.

"The particular coal handled on these trials was from the Essen mine, in western Pennsylvania. It contained a large percentage of refuse, and therefore afforded an excellent opportunity of illustrating any superiority in stoking which a mechanical device would give over hand firing. A test of a sample of the coal used gave, by a Mahler bomb calorimeter, 11,790 B. T. U. per pound of dry coal.

* The name of this vessel has since been changed to "Mataafa."



STEAM PACKET "DIRIGO"

OWNERS: J. S. KIMBALL & Co., SAN FRANCISCO, CAL. BABCOCK & WILCOX BOILERS. HEATING SURFACE, 2200 SQUARE FEET
GRATE SURFACE, 66 SQUARE FEET. THE GREAT ALASKAN GLACIER IN THE BACKGROUND

"In all, eight tests of the main engine were made. No. 1, No. 2, and No. 5 are similar, and representative of the usual power developed under ordinary steaming conditions of the vessel. Test No. 3 was made with almost maximum high-pressure cut-off; test No. 4, cutting off very nearly as short as the high-pressure valve gear would permit.

"Tests No. 6 (a, b, c) were undertaken with the sole aim of ascertaining the economy of the main engine when working under reduced boiler pressures, no account of the coal used being recorded.

"The results of these tests are not strictly comparable, on account of the irregular operation of the air pump, causing, as will be seen from an inspection of the tables, considerable variation in the vacuum obtained on the different tests. A more satisfactory comparison would have been possible had the vacuum carried been about the same at all times.

"Previous to beginning the above tests the dead plates of the furnace were thoroughly cleaned of clinker. The same operation was repeated about an hour before each test ended, particular attention being given to have the fires, as nearly as could be judged by the eye, in the same condition at both the beginning and the end. Each test was begun and finished with the stoker hoppers entirely filled; coal fired during the interval covered by the test was accurately weighed on a platform scales.

"During the tests all water fed to the boilers was delivered by the air pump through a 4-inch pipe connection from the overboard discharge of the (jet) condenser, into the upper of two tanks in the engine room, which latter were specially installed for the tests. The upper tank was mounted upon platform scales, and water flowing into it could be regulated or shut off, as desired, by means of a valve. Each tank of water, after weighing, was dropped by gravity to the lower tank, from which a suction pipe of about 8 feet in length led to the feed pump.

"All tests began with the lower or feeding tank full, and ended in the same way.

"A Barrus throttling calorimeter attached to the main steam pipe near the high-pressure cylinder was used to determine the quality of steam supplied by the boilers, and readings of the upper and lower thermometers were recorded.

"The moisture in the steam, as figured, after making due allowance for condensation in the instrument, is so infinitesimal as to be entirely negligible in the final results. The assumption has been made, therefore, that dry steam was furnished during all the tests.

"The method adopted to determine the amount of steam used by the auxiliary machinery was to condense the exhaust steam therefrom and weigh the resultant water. This condensation was accomplished by means of a cylindrical exhaust feed-water heater, of the surface condenser type, containing thirty-eight 2-inch tubes 9 feet long. The feed water on its path to the boilers passed through these tubes and condensed the exhaust steam from the auxiliaries, which was directed into the shell, and at the same time elevated its own temperature proportionately. In order to reduce the temperature of the drain from the feed heater, it was led to a coil contained within a barrel. A stream of cooling water ran into the barrel and overflowed into the bilge. Mounted upon platform scales, was another barrel which received, by gravity,

SUMMARY OF TESTS OF MACHINERY OF MINNESOTA STEAMSHIP COMPANY'S STEAMER "PENNSYLVANIA"

Number of Test	1	2	3	4	5	6-a	6-b	6-c
Date, 1899	May 28	May 30	May 30-31	May 31	June 1	June 1	June 1	June 1
Duration of tests, hours	6	6	6	6	6	3	2	1
Average boiler pressure	242	244.2	240.8	245.3	245	197.4	129.8	108.3
Steam pressure at engine	239.4	237.2	237.2	241.8	241.8	103.4	125.8	104.3
Vacuum, inches	24.35	23.56	22.73	22.71	23.67	23.40	21.60	21.56
Cut-off in high-pressure cylinder	.644	.658	.798	.542	.656	.656	.656	.656
M. E. P. reduced to low-pressure cylinder	31.48	31.70	36.93	26.24	32.01	25.71	15.59	11.87
Revolutions per minute	77.33	74.45	79.44	66.31	73.74	67.10	51.02	44.83
Indicated horse-power	1206.71	1169.77	1455.04	862.78	1168.88	855.87	304.94	261.84
Average temperature	222	213.2	219	226.5	181.5	200.1	217	218
Total pounds	122439	116136	146089	89566	98026	45987	18390	7615
Fed to boiler	103509	100167	125711	76351	88818	38818	13930	5303
Used by main engine	18930	15969	20378	13215	....	7110	4760	2312
Used by auxiliaries*	20407	19356	24348	14928	....	15312	9195	7035
Total for all purposes	17252	16694	20952	12725	....	12039	6815	5303
Used by main engine	14.30	14.27	14.40	14.75	....	15.12	17.26	20.02
Used by auxiliaries	3155	2662	3396	2203	....	2373	2380	2312
Total for all purposes	2.61	2.28	2.33	2.55	....	2.77	11.2	8.73
Exhaust steam actually sent to feed heater in per cent. of total steam used for all purposes	16.91	16.55	16.73	17.30	16.77	17.89	23.28	28.75
Per cent. of total steam used by auxiliary machinery in operation	14.78	13.02	13.08	13.33	....	10.59	17.41	18.79
Total pounds	1546	1375	13.95	14.75	....	15.50	25.88	30.36
Per cent. of moisture	14400	14200	18000	11800	14750	....	....	....
Dry coal, pounds	13925	13731	17406	11411	3.3	3.3	3.3	3.3
Total	2321	2289	2901	1902	14263	2377	....	....
Per hour	1.63	1.69	1.72	1.88	....	....	....	....
Per indicated horse-power	1.92	1.96	1.99	2.20	2.03	....	....	....
Main engine only	2183	2575	3800	2463	....	....	....	....
All machinery in use	15.68	18.75	21.83	21.58	....	....	....	....
Actual conditions	8.79	8.46	8.39	7.85	8.25	....	....	....
From and at 212 degrees	9.24	8.97	8.85	8.21	9.02	....	....	....
Actual conditions	10.43	10.41	10.74	10.01	....	....	....	....
From and at 212 degrees	10.96	11.03	11.32	10.47	....	....	....	....
Preliminary test.	Weight of coal unreliable	Auxiliary steam exhausted to atmosphere by blower engine equal to 432.8	Leak around gland of feed pump during test equals 366 pounds. Above weights corrected	Total feed water only during five hours of test	Not observed	Not observed	Not observed	Not observed

* Includes steam used by the stoker engines.

the condensed exhaust steam from the auxiliaries. As soon as the weighing barrel was filled the inflow was momentarily stopped, the weight taken, and then the condensed water rapidly discharged into the bilge.

"On May 28, three special tests were run, with the view of fixing the steam consumption of the fire-room blower and air pump, and incidentally the total steam necessary to operate the several auxiliary pumps and the steering engine, which were in use during all the tests. The power developed by the main engine, and the average weight of coal burned were about as shown in test No. 1.

STEAM CONSUMPTION OF AUXILIARY MACHINERY

Auxiliary	Steam Consumed per Hour (Pounds)			
Air pump	721	715	828	613
Feed pump	487	468	595	350
Bilge pump	275	275	320	240
Water-service pump	146	154	156	150
Auxiliary pump	330	...	...	...
Starboard dynamo	...	480	480	...
Port dynamo	671	...	...	...
Steering engine	125	125	125	125
Fire-room blower	622	692	725	550
Total	3377	2909	3229	2028

"To determine the amount of steam used in operating the stokers, the exhaust from one was led into a barrel containing a previously weighed quantity of water, and there condensed. Two tests, similarly made, gave 22.5 and 23.7 pounds, respectively, or an average of 23.1 pounds, as the hourly consumption. For all stokers the steam used per hour would, therefore, amount to 138.6 pounds.

"The cost of operating all stokers and the blower is found to be 4.29 per cent. of the total steam generated. By reason of the blower exhaust passing through the feed heater, however, the actual net cost of the stoker installation is equivalent only to 1.68 per cent. of the steam made."

Attention of the reader is particularly called to the high evaporation obtained from and at 212° per pound of coal, the average result of five tests being 8.86, which is especially good when it is remembered that the coal burned contained only 11,790 B. T. U. per pound. The average efficiency of the boiler is therefore 72.6 per cent. Again, the coal consumption per indicated horse-power would have been materially reduced had it been possible to maintain a better vacuum, the highest reading recorded being only 24.35 inches, while the average was only 23.5 inches.



S. S. "ALEXANDER McDOUGALL"—LARGEST WHALEBACK EVER CONSTRUCTED

OWNERS: BESSEMER STEAMSHIP COMPANY. BABCOCK & WILCOX BOILERS, 2500 INDICATED HORSE-POWER. LENGTH OVER ALL, 431 FEET. LENGTH ON LOAD WATER LINE, 414 FEET. MOULDED BEAM, 50 FEET. DEPTH OF HOLD, 27 FEET

TESTS OF MACHINERY OF S. S. "ALEX. McDOUGALL"*

Under direction of the Bureau and by the courtesy of the officials of the Minnesota Steamship Co., two tests were made by Lieuts. B. C. Bryan and W. W. White, U. S. N., of this Bureau, of the main machinery of the steamer "Alexander McDougall," at present the largest whaleback in service on the Great Lakes.

The main engine was designed for a maximum horse-power of about 2500 and is similar in arrangement and all essential features to the engine of the "Pennsylvania."

The auxiliary machinery, however, differs from that of the "Pennsylvania," in that the air, water service (cooler), and bilge pumps are attached to the low-pressure cross-head of the main engine; the feed pump (Deane), is independent, duplex, of the horizontal compound tandem-plunger type, having steam cylinders of 8 and 12 inches, respectively, with water cylinders of 5 inches, and a common stroke of 10 inches. Much of the other auxiliary machinery is practically the same on both ships.

Data of Main Engine	High-pressure	First Intermediate-pressure	Second Intermediate-pressure	Low-pressure
Diameter of cylinders, inches (all rods $5\frac{1}{4}$ -inch diameter)	19	28½	43	66
Stroke, inches	40	40	40	40
Net piston areas, square inches	272.7	627.12	1441.38	3410.38
Ratios of net piston areas	1 : 12.51	1 : 5.42	1 : 2.36	1
Clearances, per cent.	15	11	10	9

Steam is supplied by two boilers of the Babcock & Wilcox marine water-tubular type, built for a pressure of 250 pounds, containing 7000 square feet of heating and 128.8 square feet of grate surface. Two small one-cylinder (5 by 5) blowers, one for each boiler, with an inlet through heaters in the up-take and delivering at the back of the ash pits, supply the necessary air under forced draft for combustion of the fuel, which latter is hand-fired.

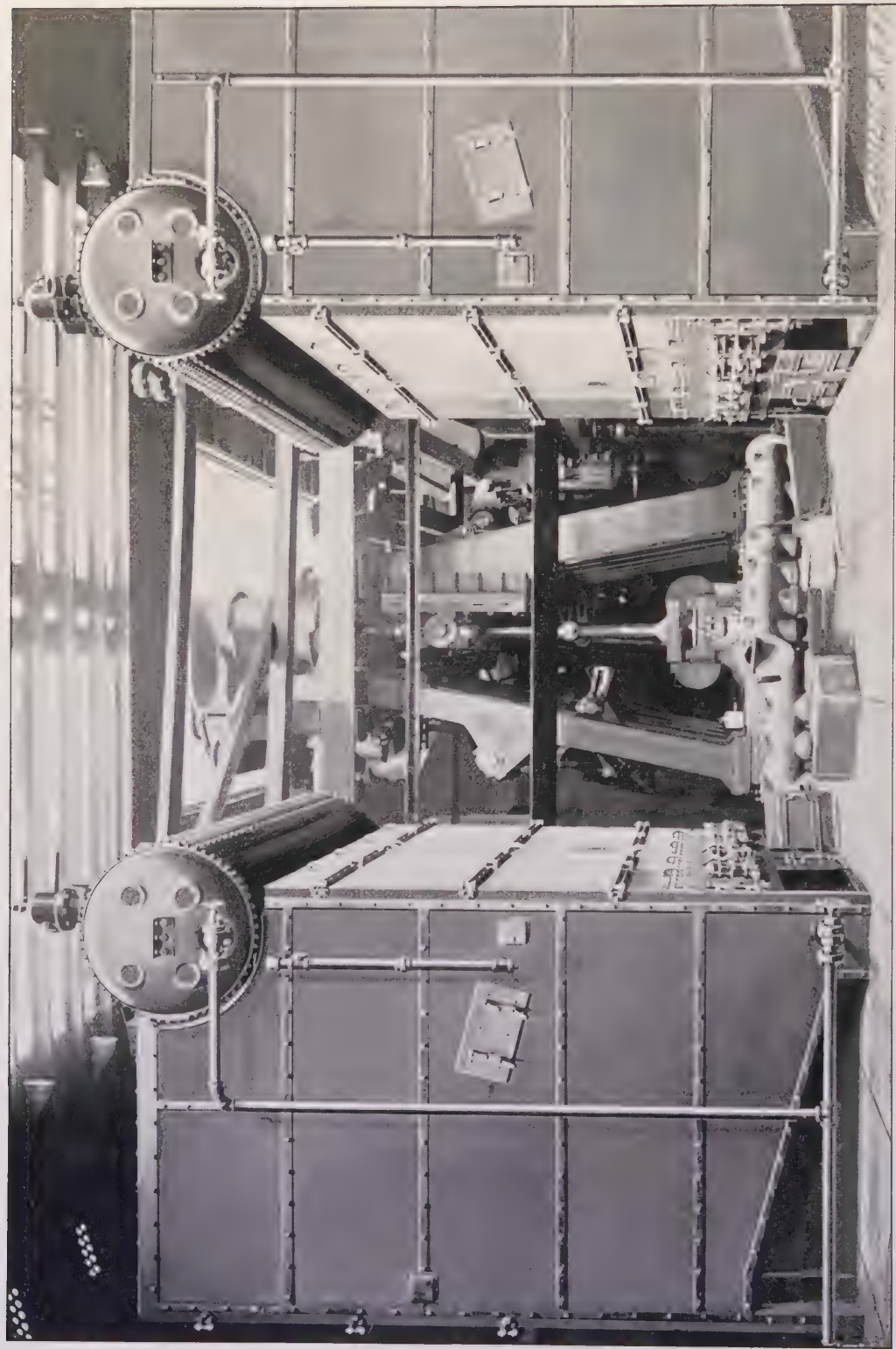
Two tests were made on the down trip, one on Lake Superior and the other on Lake Huron. The vessel was loaded with a cargo of 6407 tons (2240 pounds each) of iron ore, and had in tow the barge "Constitution," laden with 5164 tons of the same material.

The method of weighing the total water fed to the boilers, and ascertaining the steam used by the auxiliaries was, substantially, the same as in the tests of the machinery of the "Pennsylvania." A summary of results obtained appears on page 151.

At the beginning of the test on July 21, the following auxiliary machinery was in operation: Feed pump, steam-steering engine and both fire-room blowers. By reason of the feed-water heater being entirely too small, excessive back pressure resulted, and the fire-room blowers were stopped (in use one and one-fifth hours) after it became evident that steam could be readily and easily maintained at the usual pressure without their aid. The average hourly weight of condensed exhaust steam collected during five hours of the test, with the feed pump and steering engine only in use, amounted to 1685.4 pounds. For the purpose of fixing the steam economy of the feed pump during the last two and one-fourth hours of the test, the steam steering engine was thrown out and the ship steered by hand. Under the latter conditions, an average of 1174.7 pounds of condensed exhaust steam per hour resulted.

During the entire test on July 23 the only auxiliary machinery in operation was the feed pump and fire-room blowers.

* Extract from the annual report for 1899 of Admiral Geo. W. Melville, Engineer-in-chief, U. S. N.



BABCOCK & WILCOX BOILERS IN THE S. S. "ALEXANDER MCDOUGALL"

LARGEST WHALEBACK STEAMER EVER BUILT. CARRYING CAPACITY, 7000 TONS; MEAN DRAFT, 17 FEET 9 INCHES; 2500 INDICATED HORSE-POWER

SUMMARY OF TRIALS—S. S. "ALEX. McDOUGALL"

Date of trial, 1899	July 21	July 23
Duration of trial, hours	10	6
Speed of vessel, miles	8.83	9.75
Draft of vessel during trial, forward, feet	17.83	17.83
Draft of vessel during trial, aft, feet	18.00	18.00
Revolutions of engines	75.4	81.7
Piston speed, feet per minute	502.7	544.7
Pressures per gauge	Boiler 247.8 At engine 245 First receiver 96.8 Second receiver 33.1 Third receiver 2.09	244 240.7 107.5 35.2 3.2
Vacuum in condenser, inches of mercury	22.35	22.4
Opening of throttle	Wide	Wide
Steam cut-off in fractions of stroke	High-pressure .53 First intermediate-pressure .56 Second intermediate-pressure .63 Low-pressure .66	.685 .625 .655 .725
Mean pressure in cylinders	Nominal ratio of expansion 20.04 High-pressure 93.4 First intermediate-pressure 36.1 Second intermediate-pressure 15.5 Low-pressure 6.85 Equivalent reduced to low-pressure 27.57	16.39 100.90 44.56 18.88 8.31 32.60
Indicated horse-power	High-pressure 388.15 First intermediate-pressure 345.29 Second intermediate-pressure 342.85 Low-pressure 357 Total 1433.29	456.94 459.55 452.52 466.94 1835.95
Per cent. of total indicated horse-power developed in each cylinder	High-pressure 27.08 First intermediate-pressure 24.09 Second intermediate-pressure 23.92 Low-pressure 24.91 Injection 46	24.89 25.03 24.65 25.43 64
Temperature, in degrees Fahrenheit	Hot-well 117 Feed water after passing heater 170.6 Escaping gases at base of smoke pipe 543.6	115 157.8 526
Double strokes of feed pump	26.1	29.7
Revolutions of the blowers	Port * Starboard *	391 383
Air pressure, boiler ash pits, inches of water	†	.25
Kind of coal	‡	‡
Total amount of coal consumed, pounds	27200	19500
Moisture in coal, per cent.	5	5
Dry coal consumed, pounds	25840	18525
Total refuse in coal, pounds	2967	1710
Total combustible consumed, pounds	22873	16815
Quality of steam	Dry	Dry
Weighed water pumped to boilers, pounds	223996	165980
Water evaporated per pound of dry coal, boiler conditions, pounds	8.67	8.96
Water evaporated per pound of combustible, boiler conditions, pounds	9.79	9.87
Equivalent evaporation, per pound of dry coal from and at 212°	9.58	10.02
Equivalent evaporation, per pound of combustible, from and at 212°	10.82	11.03
Dry coal burned per hour per square foot of grate surface, pounds	20.06	23.07
Total steam used by main engine, pounds	207764	157346
Total steam used by auxiliary machinery, as weighed, pounds	16232	8634
Steam used by main engine per hour, per indicated horse-power developed, pounds	14.50	14.28
Total steam used (all machinery in use) per hour, per indicated horse-power developed by main engine	15.63	15.07
Dry coal used per hour per indicated horse-power to generate steam necessary to run main engine only, pounds	1.67	1.59
Dry coal used per hour per indicated horse-power, developed by main engine to generate steam required to operate all machinery in use	1.80	1.68

* Not in operation. † Natural draft. ‡ Run of mine, Pittsburg bituminous.



U. S. S. "CINCINNATI"
EIGHT BABCOCK & WILCOX BOILERS, 8000 INDICATED HORSE-POWER

TESTS OF A BABCOCK & WILCOX BOILER BUILT FOR THE U. S. S. "CINCINNATI" *

In the annual report of the Chief of the Bureau of Steam Engineering there is published a report of tests made on one of eight new boilers built by The Babcock & Wilcox Company for the "Cincinnati," by a board composed of Lieutenant-Commander A. B. Willits and Lieutenant B. C. Bryan, U. S. N. These tests were made June 15 to 22, 1900, at the works of the builders, Elizabethport, N. J., and the following synopsis includes all but the detailed tabulations from which the important data given was deduced."

DESCRIPTION OF BOILER AND APPURTENANCES

The boiler is of the Babcock & Wilcox new marine type, composed entirely of wrought steel, the point of difference between it and the older type of this make of boiler being in the arrangement of baffle plates (as shown in the sectional view on the following page) which compel the products of combustion to pass three times across the tubes before entering the up-take. The small tubes are 2 inches outside diameter, while the bottom tube in each section or element, is 4 inches outside diameter. The total heating surface is 2640 square feet.

The grate is an undivided area of 63.25 square feet, and is fired through four properly spaced doors.

BOILER DATA

Kind of boiler, Babcock & Wilcox—"Alert" type. Diameter of top drum, 42 inches, inside. Length of top drum, 12 feet. Tubes: total number, 565; length, 8 feet (525, 2 inches outside diameter, and 40, 4 inches outside diameter). Grate surface: length, 6 feet 8 $\frac{1}{4}$ inches; width, 9 feet 5 $\frac{1}{2}$ inches; area, 63.25. Grate surface reduced in tests Nos. 5 and 6, to 5 feet 6 inches; 52 square feet area. Heating surface: area, 2640 square feet; ratio to grate, 41.74:1. Per cent. water-heating surface, 100. Grate bars: kind, fixed. Smoke pipe: area, 7.876 feet; height, 48 feet above grate; ratio to grate, 1:8.03. Weight of boiler and all fittings except up-takes and smoke pipe:

Without water, pounds	5330.4
Water, 5 inches in glass; steam at 215 pounds, pounds	949.8
Total with water, pounds	6280.2
Total weight per square foot of grate surface, pounds	992.9
Total weight per square foot of heating surface, pounds	23.79

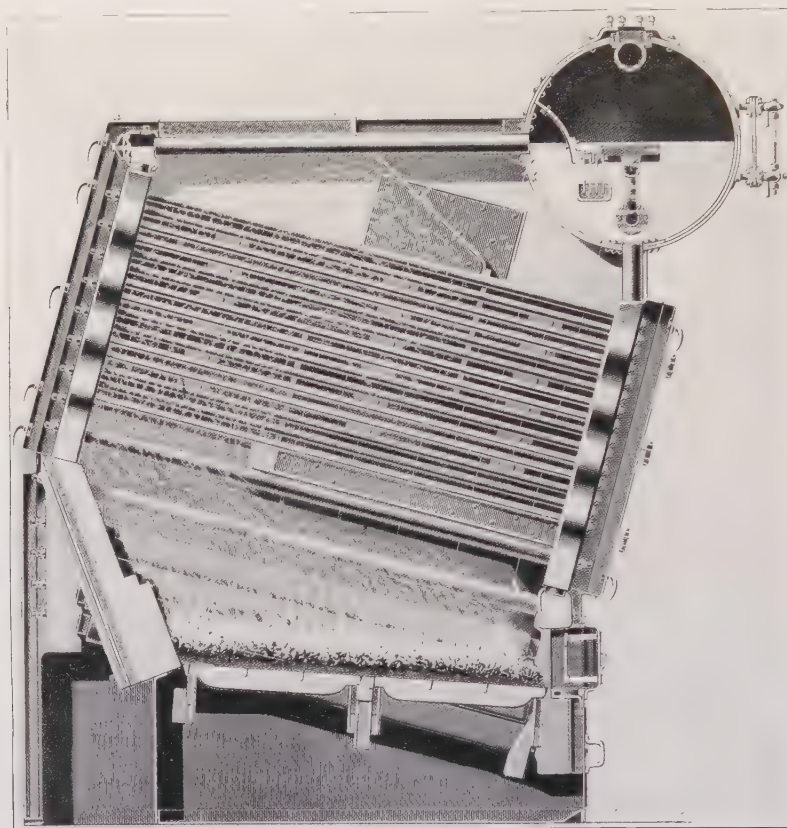
Blower: kind, 60-inch Sturtevant, driven by belt from shop engines. Area of blower inlet, 9.62 square feet; outlet, 6.89 square feet. Feed water: kind, feed water heated by steam jet. Air heater: kind, two-pass; 3-inch tubes. Area of surface, 495 square feet. Feed pumps: kind, Worthington duplex; dimensions of cylinders, 7 $\frac{1}{2}$ by 4; 6-inch stroke. Other boiler appurtenances: steam jet.

The boiler was erected in a wooden structure built especially for the test and having the following dimensions: Length, 29 feet 2 inches; width, 17 feet 2 $\frac{1}{2}$ inches;

*Extracts from the "Journal of the American Society of Naval Engineers," Volume XII.

height, 21 feet. This was made as nearly air-tight as possible, but contained several windows that could be opened or closed to regulate the amount of draft pressure. The blower was driven by belting from the main shop engines and ran continually.

An air heater was built in the up-take by means of which the waste gases imparted heat to the air on its passage to the ash pit. This heater could be placed in and out of service at will by the use of a by-pass flue.



"CINCINNATI'S" BOILER—B. & W. "ALERT" TYPE. SECTION SHOWING PATH OF GASES

DESCRIPTION AND OBJECT OF TESTS

Seven tests were made in all. Six of these consisted of three pairs, in which the tests of each pair were made under similar conditions in every way except that of using the air heater, one being with and the other being without this heater, in order to define the economy due to its use. The last or seventh test was for maximum capacity, and was made without the air heater and with the full grate. Two pairs of tests, one at a consumption of about 20 pounds of coal and the other at about 35 pounds of coal per square foot of grate per hour, were made with the full grate surface in use. These tests will be found in tables of results numbered 1, 2-H, 3-H, 4, the letter H signifying that the air heater was in use during the tests. The grate surface was then reduced to 52 square feet, by a course and a half of bricks, seven courses in

height, at the back of the furnace, and tests Nos. 5 and 6-H were made, burning about 50 pounds of coal per square foot of grate per hour. The bricks were then removed from the furnace and test No. 7 was made, burning nearly 60 pounds of coal per square foot of grate per hour. The data and results of these tests will be found in the table on pages 158 and 159.

COAL AND FIRING

The fuel used was Pocahontas, Flat Top, coal. It contained considerable slate and clinkered badly. On tests Nos. 1 and 2-H run-of-mine coal was used; on tests Nos. 3-H, 4, 5 and 6-H the coal was screened, using a screen with a 1-inch mesh. On test No. 7 the screenings from the former tests were run over a $\frac{3}{8}$ -inch mesh screen, and the coal thus screened was mixed with the screened coal used in other tests. The firing was good and very regular. Two alternate doors were fired in rapid succession. The other two sections of fires, in wake of the other two doors, were sliced through the slicing door, and then leveled with a hoe, and then coaled, the average time between coalings of the same two furnaces being from eight to ten minutes. The furnace doors were open about twenty-five seconds when coaling and about ten seconds in leveling. The coal made comparatively little smoke except when firing or working fires. The data in regard to smoke was taken by using Ringelmann charts.

DESCRIPTION OF APPARATUS

The water was weighed in two tanks, each supported on a platform scales and run into a third tank below, from which the feed pumps drew water. All pipes were above ground and in plain sight, and wherever connected to other piping or boilers, plugs were left out of T connections to show that there was no leakage. The gross and tare weights of each tank were taken, and the temperature was taken at the lower tank just as each upper tank drained into it. The feed water was heated by steam injection before entering the weighing tanks.

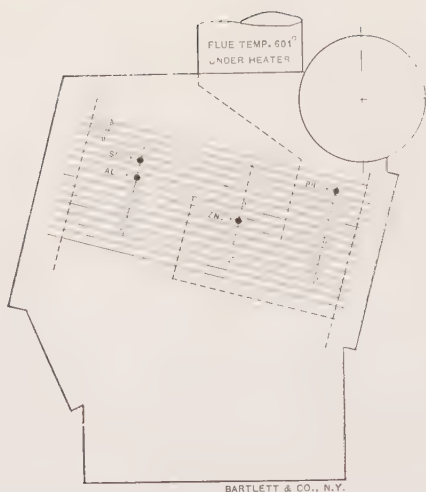
The coal was weighed in barrows on platform scales in the fire room and dumped on the floor. The time was taken when each lot of barrows were fired.

A sample shovelful of coal was taken from each lot of barrows and thrown into a barrel, and from this, mixed and quartered, the final samples for analyses, calorimeter and moisture determinations were taken. The gases for analyses were drawn from near the center of the base of smoke pipe by means of a pipe inserted therein connected with an inspirator and a small Orsat instrument.

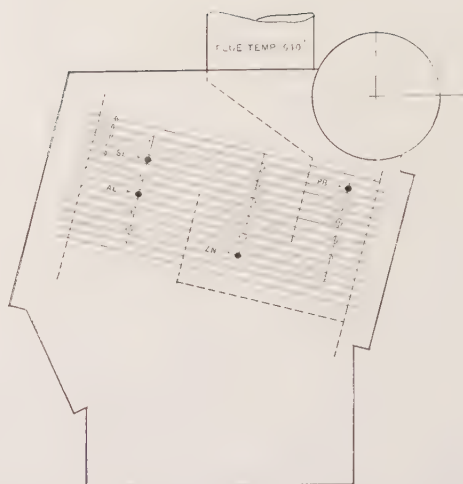
All draft pressures were taken outside the building, pipes being led there from the different places where pressure determinations were required.

Temperatures were taken at the back and front of the up-take just above the heater; in front by a mercurial pyrometer, and at the back by a metallic pyrometer. When the air heater was used the temperature was taken in addition just below the heater by means of a mercurial pyrometer.

The moisture in the steam was determined by a Barrus universal calorimeter. The steam was found practically dry in all cases. The steam was partly used in the shop and partly blown off into the atmosphere, the pressure being controlled by regulating a small stop valve by hand.



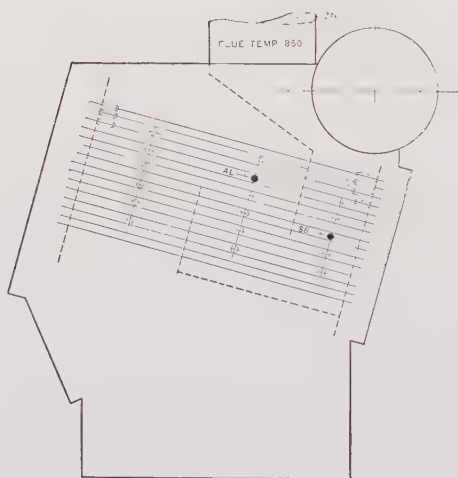
JUNE 19, 1900.—WITHOUT AIR HEATER, FULL GRATE.
COAL PER SQUARE FOOT OF GRATE PER HOUR, 35.03 POUNDS.
WATER PER SQUARE FOOT OF HEATING SURFACE, FROM
AND AT 212°, 8.75 POUNDS.



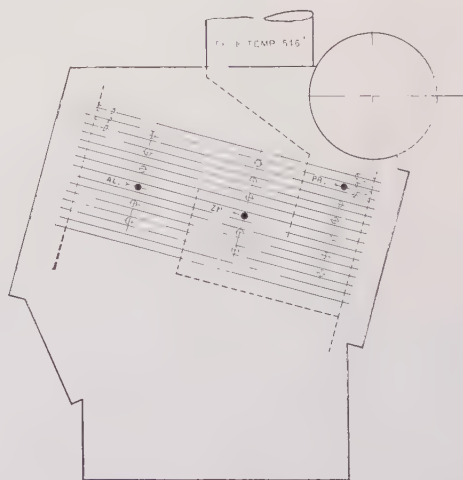
JUNE 20, 1900.—WITHOUT AIR HEATER, REDUCED GRATE.
COAL PER SQUARE FOOT OF GRATE PER HOUR, 30.38 POUNDS.
WATER PER SQUARE FOOT OF HEATING SURFACE, FROM
AND AT 212°, 10.07 POUNDS.

Al.—Aluminum melts at
Sb.—Antimony melts at
Zn.—Zinc melts at
Pb.—Lead melts at

1160° F.
840° F.
780° F.
625° F.



JUNE 22, 1900.—WITHOUT AIR HEATER, FULL GRATE.
COAL PER SQUARE FOOT OF GRATE PER HOUR, 59.2 POUNDS.
WATER PER SQUARE FOOT OF HEATING SURFACE, FROM
AND AT 212°, 13.67 POUNDS.



JUNE 25, 1900.—WITHOUT AIR HEATER, FULL GRATE.
COAL PER SQUARE FOOT OF GRATE PER HOUR, 20.18 POUNDS.
WATER PER SQUARE FOOT OF HEATING SURFACE, FROM
AND AT 212°, 5.42 POUNDS.

TEMPERATURE OF GASES PASSING THROUGH BOILER AS SHOWN BY MELTING POINT OF METALS—TESTS OF "CINCINNATI" BOILER

Experiments to show the heat of the gases at various points were made by noting the points at which different metals melted. A small piece of metal was wired to a piece of $\frac{1}{4}$ -inch pipe, and pushed in carefully through the dust doors at the side of casing to about the middle of the boiler; by noting where such metal would melt, and again introducing a piece of the same metal at another hole further along in the path of the gases until a position was reached when the metal would not melt, and by the use of various metals with known melting points, the temperature of the gases was determined and is plotted on the diagrams on the opposite page.

Before making test No. 6-H, on June 21st, all water was drained from the boiler and the contents of boiler noted for each 1-inch mark of the water gauge glass, with the following results:

WEIGHT OF WATER CONTAINED IN BOILER

TEMPERATURE OF WATER, 72 DEGREES FAHRENHEIT

Height of Water in Gauge Inches	Total Water Pounds	Difference	Height of Water in Gauge Inches	Total Water Pounds	Difference
0	9312		5	10368	231
1	9498	186	6	10672	304
2	9662	164	7	10943	271
3	9912	250	8	11175	232
4	10137	225			

Fires were started in the boilers with light wood, and blower in use, at 9:40 A. M. Temperature of water in boiler, 72 degrees; height in gauge glass, 1 inch.

The following is a record of the time required to raise steam to 215 pounds pressure from cold water:

RECORD OF RAISING STEAM

Time		Steam Pressure Pounds	Time		Steam Pressure Pounds
By Watch	Elapsed		By Watch	Elapsed	
9:40		Fires started	9:51	11 mins. 0 secs.	125
9:45	5 mins. 0 secs.	Steam formed	9:51:10	11 mins. 10 secs.	135
9:46:30	6 mins. 30 secs.	25	9:51:15	11 mins. 15 secs.	145
9:47:30	7 mins. 30 secs.	35	9:51:30	11 mins. 30 secs.	155
9:48	8 mins. 0 secs.	45	9:51:40	11 mins. 40 secs.	165
9:48:30	8 mins. 30 secs.	55	9:51:55	11 mins. 55 secs.	175
9:49	9 mins. 0 secs.	65	9:52:10	12 mins. 10 secs.	185
9:49:30	9 mins. 30 secs.	75	9:52:20	12 mins. 20 secs.	195
9:50	10 mins. 0 secs.	85	9:52:30	12 mins. 30 secs.	205
9:50:30	10 mins. 30 secs.	95	9:52:40	12 mins. 40 secs.	215
9:50:45	10 mins. 45 secs.	115			

An examination of the boiler after this test showed no injury or change in its condition in any respect.

In addition to the tests made for the Navy Department, three tests were made for The Babcock & Wilcox Company by E. H. Peabody, Mem. Am. Soc. M. E. The data and results of these tests are included with the others in the following table:

“CINCINNATI” TESTS

Lieut.-Com. A. B. Willits, U. S. N., and Lieut. B. C. Bryan, U. S. N. E. H. Peabody									
Engineers conducting tests	1	2-H	3-H	4	5	6-H	7	8	10-H
Number of tests	1	2-H	3-H	4	5	6-H	7	8	10-H
Date of tests, 1900	June 15	June 16	June 18	June 19	June 20	June 21	June 22	June 23	June 25
Duration of test, hours	8	8	6	6	4	4	3 1/2	4	4
Kind of start	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate
State of weather	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Heating surface	2640	2640	2640	2640	2640	2640	2640	2640	2640
Ratio of heating surface to grate surface	63.25	63.25	63.25	63.25	52.0	52.0	63.25	63.25	63.25
	41.74	41.74	41.74	41.74	50.8	50.8	41.74	41.74	41.74
Average Pressures									
Barometer, inches	....	30.18	30.12	30.22	30.20	30.09	30.02	....	....
Steam pressure by gauge, pounds	209.3	206.6	210.6	207.4	213.6	209.8	210.8	200.0	191
Force of draft at base of pipe, inches of water	—10	—36	+99	+13	—34	—37	—1.48	—1.99	—76
Force of draft in furnace, inches of water	+10	—09	+81	+98	+99	+95	+1.54	—55	—46
Force of draft in ash pit, inches of water	+25	+11	+1.42	+1.37	+1.95	+1.45	+1.69	—00	—32
Force of draft in closed fire room	+25	+33	+1.78	+1.44	+1.84	+2.08	+1.78	—00	—00
Average Temperatures									
External air, degrees Fahrenheit	....	84.7	80.2	75.8	80	85	90.7	....	....
Fire room, degrees Fahrenheit	101.5	99.5	98.2	101.8	109.3	115.4	117.0	114	....
Air entering heater, degrees Fahrenheit	....	93.4	94.1	....	....	106.1	....	94	....
Air leaving heater, degrees Fahrenheit	....	206.2	235.9	....	....	259.5	....	....	143
Feed water entering boiler, degrees Fahrenheit	107.5	106.2	103	101.8	103.3	102.0	99.7	....	237
Air entering ash pit, degrees Fahrenheit	101.5	206.2	235.9	101.8	109.3	259.5	117	107.4	104.8
Escaping gases from boiler, degrees Fahrenheit	466	493	608.6	570.6	640.0	637	{ Less than {	94	237
Escaping gases from heater, degrees Fahrenheit	....	458	569	....	....	674	{ 900° F. {	569	546
								....	471
Fuel									
Kind, Pocahontas coal	Run of mine	Run of mine	Screened	Screened	Screened	Screened	Twice screened	Run of mine	Twice screened
Weight of coal as fired, pounds	10345	10600	12925	13517	10600	10046	12600	9800	8630
Moisture in coal, per cent.	4.06	3.62	6.6	1.5	1.13	1.0	0.88	3.0	.75
Weight of dry coal consumed, pounds	9925	10201	12788	13314	10480	9946	12489	9506	8565
Weight of ash and refuse, pounds	996	879	1088	1268	1177	949	1055	702	5110
Weight of combustible consumed, pounds	8929	9324	11630	12046	9353	9097	11434	8609	7863
Refuse in dry coal, per cent.	10.03	8.60	8.55	9.52	11.23	9.54	8.45	9.44	4643
Fuel per Hour									
Dry coal consumed per hour, pounds	1240.6	1277	2119.7	2219	2620	2486.5	3747	2376.5	1277.5
Dry coal consumed per hour per square foot grate surface, pounds	19.61	20.19	33.51	35.08	50.38	47.81	59.23	37.54	20.18
Dry coal per hour per square foot heating surface, pounds	.470	.484	.803	.840	.992	.942	1.419	.960	.484

Quality of Steam

Per cent. of moisture in steam
 Degrees of superheating
 Quality of steam (dry steam = 100)

Water

Total weight of water feed to boiler, pounds*
 Water actually evaporated, corrected for quality of steam, pounds
 Factor of evaporation
 Equivalent water evaporated into dry steam from and at 212 degrees, pounds

Water per Hour

Water evaporated per hour, corrected for quality of steam, pounds
 Equivalent evaporation from and at 212 degrees, pounds
 Actual evaporation per square foot grate surface, pounds
 Equivalent evaporation from and at 212 degrees per square foot grate surface, pounds
 Same per square foot of heating surface, pounds

Economic Results

Water evaporated under actual conditions per pound of dry coal, pounds
 Equivalent evaporation from and at 212 degrees per pound of dry coal, pounds
 Equivalent evaporation from and at 212 degrees per pound of combustible, pounds

Efficiency

British thermal units per pound of dry coal
 Efficiency of boiler, dry coal basis

* Corrected for inequality of water level and steam pressure at beginning and end of test.

REMARKS AND OBSERVATIONS—In tests marked H the air heater was in use. Tests 8, 9 and 10-H, blower not running; stack draft increased by steam jet.

Principal data taken every fifteen and thirty minutes.

Percentage of smoke as observed, using Ringelmann smoke charts: Test 1, No. 0 to No. 1 and as high as No. 4 when firing; test 2-H, No. 0 to No. 1, with puffs of No. 4 when firing; test 3-H, No. 1 to No. 2, with puffs of No. 4 when firing; test 4, No. 2 to No. 3, with puffs of No. 4 when firing; test 5, No. 1 to No. 3, with puffs of No. 4 when firing; test 6, about No. 2, with puffs of No. 4 when firing; test 7, average about No. 3, with puffs to No. 5 when firing.

Kind of firing: Spreading and slicing.

Average thickness of fires: Tests 1 and 2-H, 6 inches; test 3-H, 7 inches; tests 4, 5, 6 and 7, 6 inches.

Average intervals between firings for each furnace during time fires were in normal condition: Eight to ten minutes.

Average interval between times of breaking up: Eight to ten minutes.

Efficiency of firemen: Expert.



WORKS OF THE COMPAGNIE FRANCAISE BABCOCK & WILCOX, PARIS, FRANCE

ANALYSES OF WASTE GASES MADE DURING TESTS OF U. S. S. "CINCINNATI" BOILER, ELIZABETHPORT, N. J., JUNE, 1900

Date	Time	Condition of Fire when Sample was Taken	CO ₂	O	CO	Pounds Dry Gas per Pound Carbon
1900	4.58	.	15.2	3.3	1.0	16.8
June 15	5.15	.	14.3	3.0	2.0	
	5.30	Just before firing	13.0	6.5	0.0	
	5.55	One minute after firing	12.5	6.7	0.8	
	6.16	Just after raking	14.3	3.7	1.0	
	6.27	Two minutes after firing	12.7	6.6	0.7	
	7.05	Three minutes after raking and just before firing	16.0	2.0	2.0	
		Average	14.0	4.5	1.1	
June 16	11.45	Just after firing	13.4	6.4	0.0	19.1
	12.50	Just after slicing	12.0	5.0	1.0	
	1.50	Just after slicing	12.0	6.6	0.2	
	3.50	Just after slicing	13.2	4.8	0.7	
		Average	12.7	5.7	0.5	
June 18	11.25	One-half minute after firing	12.3	3.4	2.7	17.3
	12.40	While slicing	14.2	4.0	0.1	
	12.50	Just after slicing	12.5	4.3	1.2	
	12.58	Just before slicing	13.0	4.0	3.4	
	1.03	One minute after firing	13.5	5.4	0.2	
		Average	13.1	4.2	1.5	
June 19	10.10	While slicing	15.0	3.2	1.2	18.8
	10.25	While slicing (all samples except 11 o'clock collected through ½-inch iron pipe)	13.8	5.2	0.6	
	10.28	Just after raking	14.4	3.1	0.9	
	10.35	One minute before firing	13.2	5.6	0.4	
	11.00	While slicing (sample collected through glass tube)	13.0	5.6	0.6	
	2.20	Just after raking	10.2	8.3	0.5	
	2.40	Just after firing	10.2	9.0	0.3	
		Average	12.8	5.7	0.6	
June 20	10.25	While slicing	13.5	5.7	0.0	20.6
	11.00	While slicing	11.2	8.4	0.3	
	11.04	Just after firing	10.4	8.1	0.5	
	11.13	Two minutes before raking	9.2	9.9	0.0	
	12.25	Just after raking	12.1	5.4	0.7	
	12.36	Just after raking	14.2	4.0	0.8	
		Average	11.8	6.9	0.4	
June 21	11.00	Just after raking	15.7	4.6	0.1	17.7
	11.03	One minute before raking	13.0	6.0	0.0	
	11.13	Just after firing	15.4	3.0	0.6	
	11.50	Just after raking	13.6	5.6	0.1	
	11.55	One minute before raking	13.0	5.3	0.4	
	11.59	Just before raking	16.0	4.2	0.0	
		Average	14.5	4.8	0.2	
June 23	11.21	Two minutes before firing	14.3	4.2	1.1	18.6
	11.45	Two minutes before firing	11.0	9.0	0.0	
	12.38	Just before leveling and firing	.....	.....	.....	
	2.26	Just after firing	11.8	7.9	0.4	
	2.30	Just after firing	13.3	4.2	1.0	
	2.43	Two minutes before firing	14.2	3.8	1.0	
		Average	12.9	5.8	0.7	
June 25	10.16	Just before firing	15.3	4.1	1.0	18.5
	10.21	One minute before firing	13.0	6.0	1.0	
	11.10	Just after leveling	13.7	6.6	0.3	
	11.13	Just after firing	14.0	5.2	0.8	
	11.47	Just after firing	9.0	11.2	0.3	
		Average	13.0	6.6	0.7	



WORKS OF BABCOCK & WILCOX, LTD., RENFREW, SCOTLAND

TESTS OF A BABCOCK & WILCOX MARINE BOILER, BUILT FOR A SEA-GOING DREDGER FOR THE INDIAN GOVERNMENT

(The tests were made at the Babcock & Wilcox Works, Renfrew, Scotland)

Date, 1899 December 28 December 29 December 30

Duration of test, hours	8	8	8
Heating surface, square feet	2835	2835	2835
Grate surface, square feet	77	77	77
Kind of fuel used	S Hetton (Newcastle)	Waynes, Merthyr (Welsh)	Black Band (Scotch)
Kind of draft	Natural	Natural	Natural
Amount of draft at root of funnel, inch	.35	.45	.4
Average gauge pressure, pounds per square inch	180	180	180
Average temperature of feed water, degrees Fahrenheit	45	40	40
Mean temperature of gases in funnel, degrees Fahrenheit	635	643	620
Total coal fired, pounds	15600	15600	15600
Total refuse, pounds	800	1680	2496
Percentage of refuse	5.1	10.7	16
Coal fired per hour, pounds	1950	1950	1950
Refuse per hour, pounds	100	210	312
Combustible per hour, pounds	1850	1740	1638
Coal consumed per square foot grate per hour, pounds	25.32	25.32	25.32
Water evaporated per hour under actual observed conditions, feed water 40 degrees Fahrenheit, pressure 180 pounds, pounds	16112	17700	15625
Equivalent weight of water evaporated per hour with feed at 110 degrees Fahrenheit, pounds	18013	19877	17546
Water evaporated per pound coal per hour, actual observed conditions, feed water 40 degrees Fahrenheit, pressure 180 pounds, pounds	8.26	9.08	8.01
Water evaporated per pound coal per hour, from and at 212 degrees Fahrenheit, pounds	10.11	11.15	9.85
Water evaporated per pound of combustible per hour, actual observed conditions, pounds	8.7	10.17	9.54
Water evaporated per pound of combustible per hour, actual observed conditions, from and at 212 degrees Fahrenheit, pounds	10.65	12.5	11.73
Water evaporated per square foot heating surface, assuming feed at 110 degrees Fahrenheit, pounds	6.3	7	6.19
Water evaporated per square foot of grate area, assuming feed at 110 degrees Fahrenheit, pounds	234	258	227
Theoretical total heat value of fuel by Thompson's calorimeter, British thermal units	13460	13660	12870
Efficiency of boiler, per cent	72.6	78.9	74

NOTE.—The evaporation obtained showed the boiler to be of a capacity suitable for a 1200 indicated horse-power triple-expansion engine of economical construction, using 14 to 15 pounds of steam per indicated horse-power per hour.

COAL CONSUMPTION TESTS OF S. S. "JOHN W. GATES"*

Between October 10 and 15, 1900, tests were made on the lake steamer "John W. Gates," owned by the American Steamship Co., by Lieutenant-Commander J. H. Perry and Lieutenant B. C. Bryan, U. S. N.

Four tests in all were made, of ten, four, eight and six hours' duration, respectively. During the tests indicator cards were taken from the main engines, and the usual observations of pressures and temperatures recorded. The coal was carefully weighed and logged on each test.

* Extracts from "Journal of the American Society of Naval Engineers," Vol. XII.

Tests Nos. 1 and 2 were made with the vessel light, on the up trip, in Lakes Huron and Superior, respectively. Test No. 1 was made under the usual running speed of the vessel when light, and amounted to merely weighing coal and taking observations for ten hours out of the run. Test No. 2 was made using a steam jet in the smoke pipe to increase the draft.

Tests Nos. 3 and 4 were made on the down trip, after having loaded at Two Harbors, Minn., with about 7000 tons of ore, the vessel drawing about 17 feet 10 inches of water. Test No. 3 was made at the usual running speed, and Test No. 4 with draft increased by steam jet in smoke pipe.

The machinery of this ship was built under the supervision of the able Chief Engineer of the American Steamship Co., Mr. Joseph F. Hayes, and the great economy obtained is largely due to his care in the design and arrangement of the plant. The ratio of the high to low-pressure cylinder area is 1 to 13.22. Joy valve gear is used on the high and intermediate-pressure cylinders, giving in the high-pressure cylinder an admission of steam almost perfect, as is shown by the indicator cards therefrom. The cylinder ports are made large, while the clearance is reduced as much as possible. A feed heater is provided, into which all the auxiliaries necessary for heating the feed water are exhausted. The dynamo when running exhausts into the third receiver of the main engine, and all precautions have been taken to make these engines economical, and with great success, as is shown by the results.

The type of Babcock & Wilcox boiler adopted, known as the "Alert" type, is one that the recent tests made by Government officials show to be exceedingly economical under various conditions. It is provided with baffle plates directing the products of combustion three times across the tubes before leaving the boiler. Each of the two boilers installed is 10 feet long, 11 feet 8 inches wide, and 13 feet 10 inches high, containing 3000 square feet of heating surface and suitable for 65 to 70 square feet of ordinary grate surface for hand firing. The total grate surface of all stokers is 108 square feet.

The weight of the two boilers dry is 109,260 pounds, and with water, 132,590 pounds.

The bottom and top rows of tubes are 4 inches in diameter and all others are 2 inches in diameter. All tubes are of seamless cold-drawn steel, the 4-inch tubes being No. 6 B. W. G., and the 2-inch tubes No. 10 B. W. G. in thickness. The lengths between headers is 9 feet.

The main propelling engine is of the vertical, direct-acting, inverted, jet-condensing, quadruple-expansion type.

Number of cylinders		4
Diameter of cylinders, in inches	High-pressure	16½
	First intermediate-pressure	25
	Second intermediate-pressure	38½
	Low-pressure	60
Stroke, inches		40
Diameter of piston rods, inches		4¾

Order of cylinders from forward: (1) high pressure, (2) first intermediate pressure, (3) second intermediate pressure, (4) low pressure. Sequence of cranks: high pressure, low pressure, first intermediate, second intermediate.

The high pressure and first intermediate pressure are at 180 degrees, as are the second intermediate pressure and low pressure, the former being at 90 degrees with the latter.

There is one four-bladed propeller, 14 feet in diameter with 15 feet 6 inches pitch.

Two mechanical stokers of the Crowe pattern were fitted to each boiler. This stoker consists, essentially, of a set of bars carried from front to back of the furnace, over a number of fair leaders, by two chains, one on each side of the furnace. At the back of the furnace the chains and bars pass over a drum and thence back over fair leaders to the front of the furnace again.

During the entire trip the stokers worked satisfactorily. During most of the time little or no smoke was emitted from the pipe except while the fires were being worked from the back, or when an additional amount of coal worked in under the plate in the front of the furnace. The air pump worked regularly and quietly, but for some reason, probably due to the large clearance required in the cylinders of this type of pump, the vacuum carried was not much in excess of $23\frac{1}{2}$ inches.

Lead did not melt during any of the tests when suspended in the up-takes just over the top row of 4-inch tubes or practically where the gases leave the boiler proper.

Lead suspended in the boiler where the gases leave the last row of 2-inch tubes melted on the test of October 15, but only softened on the tests of October 10 and 13.

A proximate analysis of the coal used, gave results as follows:

	Per cent
Fixed carbon	57.00
Volatile matter	37.00
Moisture	2.00
Ash	4.00
	100.00
Heating value of coal by calorimeter	13,180 B. T. U.

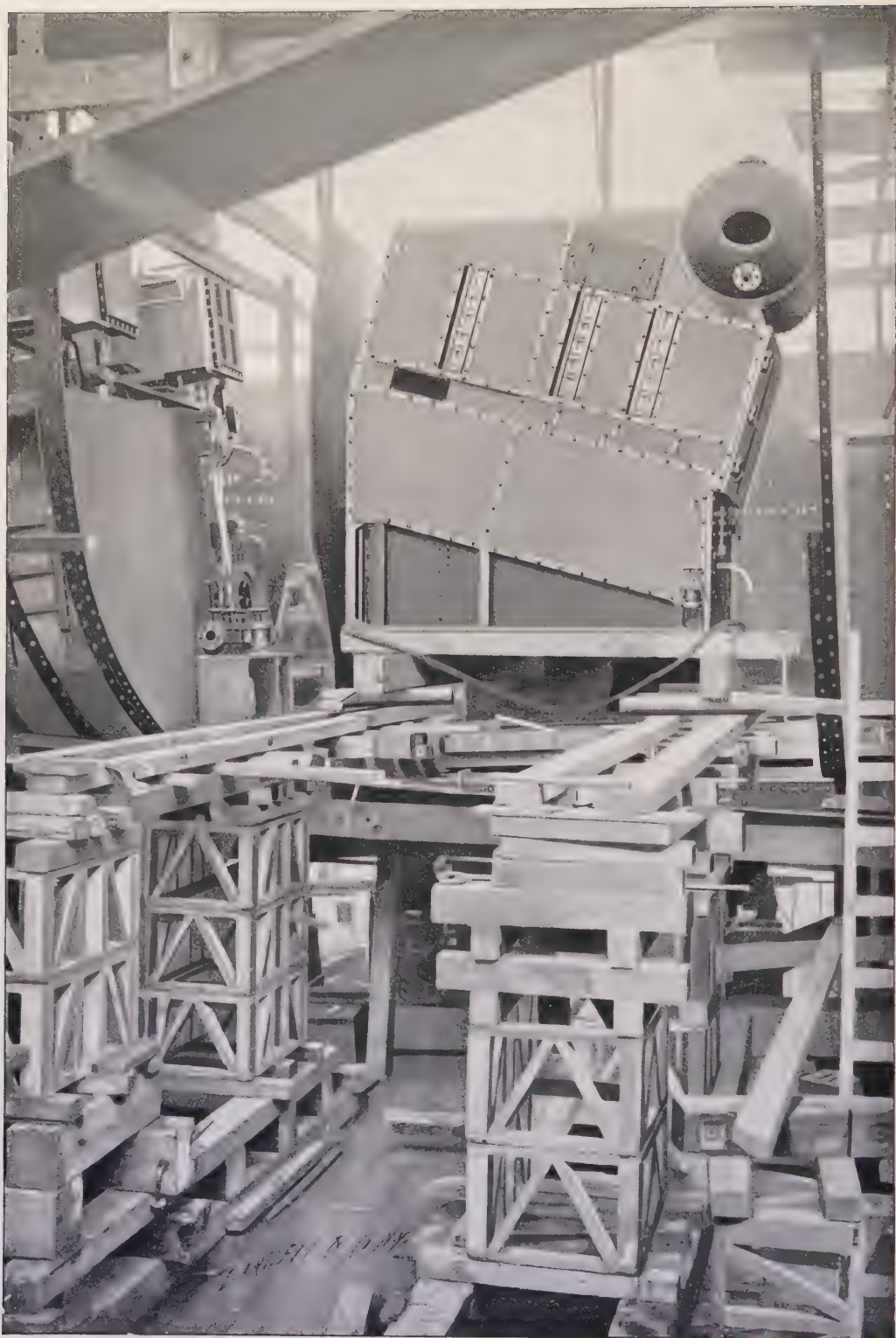
The following table gives the data and results of the tests:

COAL CONSUMPTION OF S. S. "JOHN W. GATES."

Number of test Date, 1900	1 Oct. 10	2 Oct. 11	3 Oct. 13	4 Oct. 15
Duration of test, hours	10	4	8	6
Steam pressure, pounds { At boiler	244	244	248	250
{ 1st receiver	107.8	113.9	107.7	108.7
{ 2nd receiver	32.4	34.1	32.9	34.0
{ 3d receiver	7.5	7.9	6.5	9.0
Vacuum, inches	24	23.3	23.3	23.0
Temperature, degrees { Engine room	83.5	82.7	80.0	76.2
{ Injection water	61.3	53.6	50.0	61.3
{ Hot well feed water entering heater	113.5	113.9	117.3	115.3
{ Feed water leaving heater	186.0	179.7	187.0	186.5
Links in from full throw, inches { High-pressure	3.0	.75	3.25	.75
{ 1st intermediate-pressure	3.5	1.5 to 2.25	3.75	1.00
{ 2nd intermediate-pressure	3.5	1.75 to 2.25	3.75	1.50
{ Low-pressure	4.5	1.75	3.75	2.25
Indicated horse-power main engine { High-pressure cylinder	340.1	425.6	330.2	437.8
{ 1st intermediate-pressure cylinder	388.5	516.6	354.2	490.7
{ 2nd intermediate-pressure cylinder	340.1	417.9	346.5	390.0
{ Low-pressure cylinder	362.0	458.2	312.7	465.9
{ Total	1430.7	1818.3	1343.6	1784.4
Revolutions per minute, main engine	82.77	89.8	77.84	85.36
Coal { Total coal, moist, pounds	22270	14535	17099	20655
{ Moisture in coal, per cent	4.1	4.1	4.1	4.1
{ Coal per hour, dry, pounds	2135.7	3488.7	2049.8	3301.4
{ Dry coal per hour per square foot of grate surface, pounds	19.77	32.26	19.98	30.58
Coal per indicated horse-power main engine, pounds { Coal as fired	1.56	1.998*	1.59	1.93*
{ Dry coal	1.50	1.92	1.53	1.85
Draft in up-take, inches of water	.30	Jet in funnel	.33	Jet in funnel
Temperature of waste gases	Lead did not melt	Lead did not melt	Lead did not melt	Lead did not melt
Time dynamo engine was in operation	3 hours	2 hours	55 minutes	Not running
Double strokes per minute { Air pump, high pressure	22	23.7	20.1	19.0
{ Air pump, low pressure	19	22	18.8	16.2
{ Feed pump	18	24	18.7	23.8

* The increase in coal consumption per indicated horse-power is caused by the waste of steam due to increasing the draft by means of a steam jet in the funnel. This jet was supplied by a $1\frac{1}{2}$ -inch pipe and nearly doubled the draft.

AUXILIARIES IN OPERATION: Air pump, feed pump, stoker engine and dynamo engine part of time, as noted above.



METHOD OF INSTALLING BABCOCK & WILCOX BOILERS IN THE S. S. "KVICHAK"

While the vessel was still on the stocks, an opening was left in the side opposite the boiler space. The boilers were raised on crib work, and slid through the opening on to their foundations, after which the frames were erected and the plating completed.

LIST OF VESSELS

IN WHICH BABCOCK & WILCOX BOILERS ARE FITTED OR ARE ON ORDER

Name	No. of Boilers	Indicated Horse-power	Year	Owner
Yacht "Reverie" . . .	1	250	1889	F. G. Bourne, New York
Yacht "Trophy" . . .	1	200	1891	E. H. Bennett, New York
Yacht "Eleanor" . . .	1	200	1891	P. Lancaster, Surrey, Eng.
S. S. "Nero" . . .	1	500	1891	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
S. S. "Hero" . . .	2	1,300	1895	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
S. S. "Turret Crown" . . .	2	1100	1895	Petersen, Tate & Co., Newcastle, Eng.
S. S. "Turret Cape" . . .	2	1100	1895	Petersen, Tate & Co., Newcastle, Eng.
Yacht "Seneca" . . .	1	400	1895	Chas. Fletcher, Providence, R. I.
S. S. "Zenith City" . . .	2	2000	1895	Zenith Transit Co., Duluth, Minn.
S. S. "Cameo" . . .	2	1,300	1895	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
Tug "Rodney" . . .	1	200	1895	S. Williams & Sons, Dagenham, Eng.
S. S. "Scottish Hero" (Main)	2	1,450	1895	Petersen, Tate & Co., Newcastle, Eng.
S. S. "Scottish Hero" (Donkey)	1	250	1895	Petersen, Tate & Co., Newcastle, Eng.
S. S. "Queen City" . . .	2	2000	1896	Zenith Transit Co., Duluth, Minn.
Tug "Edna G." . . .	1	550	1896	Duluth & Iron Range R. R., Port Duluth
U. S. Gunboat "Annapolis" . . .	2	1,300	1896	United States Navy
U. S. Gunboat "Marietta" . . .	2	1,300	1896	United States Navy
S. S. "Norefjeld" . . .	1	100	1896	Akers Mek. Varksted, Christiania
Tug "Duke" . . .	1	120	1896	S. Williams & Sons, Dagenham, Eng.
Tug "Benbow" . . .	1	200	1896	S. Williams & Sons, Dagenham, Eng.
S. S. "Turret Chief" . . .	2	1100	1896	Petersen, Tate & Co., Newcastle, Eng.
S. S. "Turret Court" . . .	2	1100	1896	Petersen, Tate & Co., Newcastle, Eng.
S. S. "Mahomet Ali" . . .	1	225	1896	Thos. Cook & Son, Ltd., Cairo, Egypt
S. S. "Rameses" . . .	2	375	1896	Thos. Cook & Son, Ltd., Cairo, Egypt
Cruiser "Chicago" . . .	6	5000	1896	United States Navy
H. M. S. "Sheldrake" . . .	4	3500	1896	British Navy
S. S. "Orlando" . . .	2	1200	1896	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
S. S. "Rollo" . . .	2	1,400	1896	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
Tug "Pier" . . .	1	400	1896	New York City Dock Department
S. S. "Crescent City" . . .	2	2000	1896	Zenith Transit Co., Duluth, Minn.
S. S. "Empire City" . . .	2	2000	1896	Zenith Transit Co., Duluth, Minn.
P. S. "Konstantin Arzibouchev" . . .	1	600	1897	Navsky Mech. Works, St. Petersburg
Tug "Hotspur" . . .	2	800	1897	London and India Docks Joint Committee
S. S. "Otto" . . .	2	1,500	1897	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
S. S. "Truro" . . .	2	1,500	1897	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
S. S. "Superior City" . . .	2	2000	1897	Zenith Transit Co., Duluth, Minn.
S. S. "Alex. McDougall" . . .	2	2,500	1897	Bessemer S. S. Co., Cleveland, Ohio
S. S. "Presque Isle" . . .	2	2000	1897	Presque Isle Transportation Co., Cleveland, Ohio
Dredger "Volga" . . .	8	5600	1897	Russian Government
S. W. Tender "Zaritzen" . . .	1	300	1897	Russian Government
Dredger "Anteleon" (sea-going)	2	700	1897	New South Wales Government
Cruiser "Atlanta" . . .	4	2000	1897	United States Navy
S. S. "Dirigo" . . .	1	650	1897	J. S. Kimball & Co., San Francisco, Cal.
P. S. "Oonas" . . .	1	125	1898	Thos. Cook & Son, Ltd., Cairo, Egypt
S. S. "Chas. Nelson" . . .	2	850	1898	Chas. Nelson, San Francisco, Cal.
Monitor "Manhattan" . . .	2	1,500	1898	United States Navy

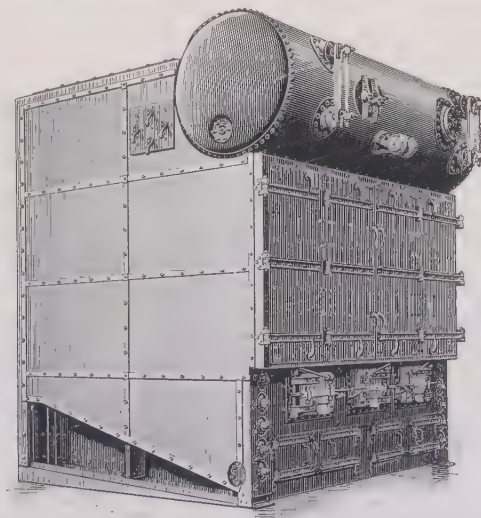
LIST OF VESSELS IN WHICH BABCOCK & WILCOX BOILERS ARE FITTED
OR ARE ON ORDER—*Continued*

Name	No of Boil- ers	Indi- cated Horse- power	Year	Owner
Monitor "Mahopac"	2	1500	1898	United States Navy
Monitor "Canonicus"	2	1500	1898	United States Navy
Corvette "Ellida"	2	700	1898	Norwegian Navy
S. S. "Arlanza"	1	150	1898	Spanish Navy
S. S. "Tasso"	2	1500	1898	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
Tug "Sirdar"	2	900	1898	London & India Docks, Joint Committee
* S. S. "Mataafa"	2	2000	1898	Minnesota S. S. Co., Cleveland, Ohio
Yacht "Magpie"	1	60	1899	Thomson & Campbell
Cruiser "Alert"	2	1560	1899	United States Navy
S. S. "City of Nanaimo"	1	750	1899	Esquimalt & Nanaimo Ry. Co., Victoria B. C.
S. S. "Maliotoa"	2	2000	1899	Minnesota S. S. Co., Cleveland, Ohio
S. S. "Maunaloa"	2	2000	1899	Minnesota S. S. Co., Cleveland, Ohio
Monitor "Wyoming"	4	2400	1899	United States Navy
P. S. "Berusa"	1	650	1899	Sevecke Steamship Co.
P. S. "Serapis"	1	125	1899	Thos. Cook & Son, Ltd., Cairo, Egypt (4th order)
S. S. "Beskytteren"	2	600	1899	Danish Navy Fishery Control Steamer
S. S. "Kvichak"	2	650	1899	Alaska Packer Association, San Francisco, Cal.
Dredger "Lindon Bates"	1	600	1899	Indian Government
Dredger "Hercules"	4	2600	1899	Queensland Government
Dredger "Samson"	6	4900	1899	Queensland Government
Dredger "Archer"	4	2000	1899	Queensland Government
H. M. S. "Espiegle"	2	1400	1899	British Navy
S. S. "Martello"	4	2500	1899	Thos. Wilson, Sons & Co., Ltd., Hull, Eng.
S. S. "John S. Kimball"	2	1075	1899	J. S. Kimball & Co., San Francisco, Cal.
S. S. "Noyo"	1	540	1899	J. S. Kimball & Co., San Francisco, Cal.
S. S. "Mongolian"	1	400	1899	J. & A. Allen, Glasgow, Scotland
S. S. "Numidian"	1	400	1899	J. & A. Allen, Glasgow, Scotland
S. S. "Rainier"	2	900	1899	Pollard & Dodge, San Francisco, Cal.
S. S. "Robert Dollar"	2	550	1899	Robert Dollar, San Francisco, Cal.
S. S. "Nome City"	2	700	1899	Gray & Mitchell, San Francisco, Cal.
S. S. "Santa Ana"	1	700	1899	Beadle & Co., San Francisco, Cal.
Cruiser "Cincinnati"	8	8000	1900	United States Navy
S. S. "John W. Gates"	2	2000	1900	American Steel & Wire Co.
S. S. "James J. Hill"	2	2000	1900	American Steel & Wire Co.
S. S. "Isaac L. Ellwood"	2	2000	1000	American Steel & Wire Co.
S. S. "Wm. Edenborn"	2	2000	1900	American Steel & Wire Co.
S. S. "Shelikof"	1	450	1900	Pacific Whaling Co., San Francisco, Cal.
Fire Boat "W. S. Grattan"	2	900	1900	City of Buffalo
S. S. "Harvard"	2	2300	1900	Pittsburg S. S. Co., Cleveland, Ohio
S. S. "Lafayette"	2	2300	1900	Pittsburg S. S. Co., Cleveland, Ohio
S. S. "Princeton"	2	2300	1900	Pittsburg S. S. Co., Cleveland, Ohio
S. S. "Cornell"	2	2300	1900	Pittsburg S. S. Co., Cleveland, Ohio
S. S. "Rensselaer"	2	2300	1900	Pittsburg S. S. Co., Cleveland, Ohio
Dredge "Texas City"	1	1055	1900	J. R. Myers, Houston, Texas
S. S. "Coronado"	1	573	1900	Pollard & Dodge, San Francisco, Cal.
S. S. "Santa Barbara"	1	661	1900	J. R. Hanify & Co., San Francisco, Cal.
S. S. "Paraguay"	2	1500	1900	International S. S. Co., Duluth, Minn.

* Formerly "Pennsylvania."

LIST OF VESSELS IN WHICH BABCOCK & WILCOX BOILERS ARE FITTED
OR ARE ON ORDER—*Continued*

Name	No. of Boil- ers	Indi- cated Horse- power	Year	Owner
S. S. "Asuncion" . . .	2	1500	1900	International S. S. Co., Duluth, Minn.
S. S. "Spokane" . . .	3	2500	1900	Pacific Coast Co., San Francisco, Cal.
Cruiser "Raleigh" . . .	8	8000	1900	United States Navy
Cruiser "Denver" . . .	6	4500	1900	United States Navy
Cruiser "Chattanooga" . . .	6	4500	1900	United States Navy
Cruiser "Galveston" . . .	6	4500	1900	United States Navy
Cruiser "Tacoma" . . .	6	4500	1900	United States Navy
Cruiser "Des Moines" . . .	6	4500	1900	United States Navy
Cruiser "Cleveland" . . .	6	4500	1900	United States Navy
Cruiser "Challenger" . . .	18	12500	1900	British Navy
Sloop "Odin" . . .	4	1400	1900	British Navy
S. S. "Chehalis" . . .	2	750	1900	Sudden & Christianson, San Francisco, Cal.
S. S. "Franklin H. Peavey" . . .	2	2000	1901	Peavey S. S. Co., Duluth, Minn.
S. S. "George W. Peavey" . . .	2	2000	1901	Peavey S. S. Co., Duluth, Minn.
S. S. "F. T. Heffelfinger" . . .	2	2000	1901	Peavey S. S. Co., Duluth, Minn.
S. S. "F. B. Wells" . . .	2	2000	1901	Peavey S. S. Co., Duluth, Minn.
Cruiser "St. Louis" . . .	16	21000	1901	United States Navy
Cruiser "Milwaukee" . . .	16	21000	1901	United States Navy
H. M. S. . . .	15	1500	1901	British Navy
S. S. "Arctic" . . .	1	575	1901	J. S. Kimball & Co., San Francisco, Cal.
Cruiser "California" . . .	30	23000	1901	United States Navy
Cruiser "South Dakota" . . .	30	23000	1901	United States Navy
Battle ship "Nebraska" . . .	24	19000	1901	United States Navy
H. M. S. . . .	24	22000	1901	British Navy
H. M. S. . . .	24	22000	1901	British Navy
H. M. S. . . .	24	22000	1901	British Navy





FIRE BOAT AND ICE BREAKER "W. S. GRATTAN"

OWNERS: CITY OF BUFFALO. BABCOCK & WILCOX BOILERS, 900 INDICATED HORSE-POWER

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